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Vector Mechanics for Engineers
Statics
(Third SI Metric Edition)

工程师的矢量力学
静力学 （国际单位制第3版）

Ferdinand P. Beer E. Russell Johnston Jr.

清华大学出版社

THIRD SI METRIC EDITION

Vector Mechanics for Engineers

STATICS

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[1] IE=International Edition

Vector Mechanics for Engineers　Statics

(Third SI Metric Edition)

影印版序

本书是美国采用得最多的“工程力学”著名教材之一，由里海大学的 F. P. Beer 教授和康奈狄克大学的 E. R. Johnston 教授合著。本书自 1962 年首版以来已经出版了 6 版。世界上已有超过 350 万的大学生通过本书学习力学的基本概念和基本原理。

牛顿于 17 世纪末创立的力学基本原理已经成为当今工程科学的基石。高等理工院校多数专业的大学生都要学习力学基础课。美国的“工程力学”课程分为静力学和动力学两部分，基本上相当于我国的“理论力学”课程，只是作为选讲内容在静力学中增加了有关梁的内力分析的内容，这在我国是由“材料力学”课程讲授的。

本册是该教材的第 1 部分——静力学。第 1 章是引言。第 2 章讲质点静力学，包括受平面力和空间力的两种情况。第 3 章讨论力系的等效。第 4 章讲刚体的平衡。第 5 章论述分布力系、形心与重心。第 6 章研究结构分析，包括桁架、刚架和机构。第 7 章是梁和悬索中的内力。第 8 章讲摩擦。第 9 章讨论惯性矩。第 10 章介绍虚功方法。其中供教师自由选讲的章节在目录中加有*号，第 7 和第 10 章被整章列为选讲内容。附录中给出国际单位和美国常用单位间的转换关系。

牛顿力学研究的主要物理量都是矢量，例如矢径、位移、速度和角速度、加速度和角加速度、力和力矩等，所以又称为“矢量力学”。有些教材回避矢量运算来讲牛顿力学就很难讲明三维问题和一般规律。本书的重要特点是基于矢量运算和矢量分析来讲述牛顿力学，因而推导过程简明清晰，所得结论具有一般性，实现了严密的逻辑演绎和清晰的物理概念的紧密结合。作者强调指出，矢量运算是一个数学工具，重点要抓住对力学基本概念和基本原理的正确理解，并学会将力学原理应用于求解工程实际问题的技巧。

本书另一个特点是阐述由浅入深、循序渐进。例如先通过较为简单的“质点力学”讲解基本概念和基本原理，然后再深入讲授较难的“刚体力学”问题；先不用矢量运算讲明平面问题，然后再引入矢量运算讲授三维一般情况。

本书第三个特点是基于作者丰富的教学经验对教材内容和讲解顺序作了精心的安排。每章分为若干单元，每个单元相当于一堂课，先讲理论，再讲应用例题，然后有供学生复习用的思考题，最后给出大量习题，习题还按由易到难的顺序排列。每章末给出简短的评论和小结，最后有适合用微机编程求解的作业（编号中都带字母 C）。本书共计有 1400 余道习题，其中 70%附有答案。没有答案的习题的编号用斜体印刷。

本书对数学基础的要求是：代数、三角、初等微积分和矢量代数，对二年级大学生来说这要求并不高。

本书附有基于 Windows 的交互式软件，内容包括使用动画讲述基本概念以及给出更多的例题和检测题。

本书内容难度介于我国理论力学多学时和中学时的教学要求之间，概念清晰、推理严谨、论述简明易懂、应用灵活多样、习题丰富，是一本优秀的工程力学教材，可作为我国高等理工院校理论力学和工程力学课程的英文教材或主要参考书。

陆明万
清华大学工程力学系

About the Authors

"How did you happen to write your books together, with one of you at Lehigh and the other at UConn, and how do you manage to keep collaborating on their successive revisions?" These are the two questions most often asked of our two authors.

The answer to the first question is simple. Russ Johnston's first teaching appointment was in the Department of Civil Engineering and Mechanics at Lehigh University. There he met Ferd Beer, who had joined that department two years earlier and was in charge of the courses in mechanics. Born in France and educated in France and Switzerland (he holds an M.S. degree from the Sorbonne and an Sc.D. degree in the field of theoretical mechanics from the University of Geneva), Ferd had come to the United States after serving in the French army during the early part of World War II and had taught for four years at Williams College in The Williams-MIT joint arts and engineering program. Born in Philadelphia, Russ had obtained a B.S. degree in civil engineering from the University of Delaware and an Sc.D. degree in the field of structural engineering from MIT.

Ferd was delighted to discover that the young man who had been hired chiefly to teach graduate structural engineering courses was not only willing but eager to help him reorganize the mechanics courses. Both believed that these courses should be taught from a few basic principles and that the various concepts involved would be best understood and remembered by the students if they were presented to them in a graphic way. Together they wrote lecture notes in statics and dynamics, to which they later added problems they felt would appeal to future engineers, and soon they produced the manuscript of the first edition of *Mechanics for Engineers*.

The second edition of *Mechanics for Engineers* and the first edition of *Vector Mechanics for Engineers* found Russ Johnston at Worcester Polytechnic Institute and the next editions at the University of Connecticut. In the meantime, both Ferd and Russ had assumed administrative responsibilities in their departments, and both were involved in research, consulting, and supervising graduate students—Ferd in the area of stochastic processes and random vibrations, and Russ in the area of elastic stability and structural analysis and design. However, their interest in improving the teaching of the basic mechanics courses had not subsided, and they both taught sections of these courses as they kept revising their texts and began writing the manuscript of the first edition of *Mechanics of Materials*.

This brings us to the second question: How did the authors manage to work together so effectively after Russ Johnston had left Lehigh? Part of the answer is provided by their phone bills and the money they have spent on postage. As the publication date of a new edition approaches, they call each other daily and rush to the post office with express-mail packages. There are also visits between the two families. At one time there were even joint camping trips, with both families pitching their tents next to each other. Now, with the advent of the fax machine, they do not need to meet so frequently.

Their collaboration has spanned the years of the revolution in computing. The first editions of *Mechanics for Engineers* and of *Vector Mechanics for Engineers* included notes on the proper use of the slide rule. To guarantee the accuracy of the answers given in the back of the book, the authors themselves used oversize 20-inch slide rules, then mechanical desk calculators complemented by tables of trigonometric functions, and later four-function electronic calculators. With the advent of the pocket multifunction calculators, all these were relegated to their respective attics, and the notes in the text on the use of the slide rule were replaced by notes on the use of calculators. Now problems requiring the use of a computer are included in each chapter of their texts, and Ferd and Russ program on their own computers the solutions of most of the problems they create.

Ferd and Russ's contributions to engineering education have earned them a number of honors and awards. They were presented with the Western Electric Fund Award for excellence in the instruction of engineering students by their respective regional sections of the American Society for Engineering Education, and they both received the Distinguished Educator Award from the Mechanics Division of the same society. In 1991 Russ received the Outstanding Civil Engineer Award from the Connecticut Section of the American Society of Civil Engineers, and in 1995 Ferd was awarded an honorary Doctor of Engineering degree by Lehigh University.

A new collaborator, Elliot Eisenberg, Professor of Engineering at the Pennsylvania State University, has joined the Beer and Johnston team for this new edition. Elliot holds a B.S. degree in engineering and an M.E. degree, both from Cornell University. He has focused his scholarly activities on professional service and teaching, and he was recognized for this work in 1992 when the American Society of Mechanical Engineers awarded him the Ben C. Sparks Medal for his contributions to mechanical engineering and mechanical engineering technology education and for service to that society and to the American Society for Engineering Education.

And finally, there are the contributions of Theodore Wildi to the integrated conversion of this Third SI Metric Edition. He is Chair of the CSA Technical Committee on the International System of Units and author of *Metric Units and Conversion Charts*, a widely used handbook for professional engineers.

Preface

The main objective of a first course in mechanics should be to develop in the engineering student the ability to analyze any problem in a simple and logical manner and apply to its solution a few, well-understood basic principles. It is hoped that this text, designed for the first course in statics offered in the sophomore year, and the volume that follows, *Vector Mechanics for Engineers: Dynamics*, will help the instructor achieve this goal.[†]

Vector algebra is introduced early in the text and is used in the presentation and the discussion of the fundamental principles of mechanics. Vector methods are also used to solve many problems, particularly three-dimensional problems where these techniques result in a simpler and more concise solution. The emphasis in this text, however, remains on the correct understanding of the principles of mechanics and on their application to the solution of engineering problems, and vector algebra is presented chiefly as a convenient tool.[‡]

One of the characteristics of the approach used in these volumes is that the mechanics of *particles* has been clearly separated from the mechanics of *rigid bodies*. This approach makes it possible to consider simple practical applications at an early stage and to postpone the introduction of more difficult concepts. In this volume, for example, the statics of particles is treated first (Chap. 2); after the rules of addition and subtraction of vectors have been introduced, the principle of equilibrium of a particle is immediately applied to practical situations involving only concurrent forces. The statics of rigid bodies is considered in Chaps. 3 and 4. In Chap. 3, the vector and scalar products of two vectors are introduced and used to define the moment of a force about a point and about an axis. The presentation of these new concepts is followed by a thorough and rigorous discussion of equivalent systems of forces leading, in Chap. 4, to many practical applications involving the equilibrium of rigid bodies

[†]Both texts are also available in a single volume, *Vector Mechanics for Engineers: Statics and Dynamics*, sixth edition.

[‡]In a parallel text, *Mechanics for Engineers: Statics*, fourth edition, the use of vector algebra is limited to the addition and subtraction of vectors.

under general force systems. In the volume on dynamics, the same division is observed. The basic concepts of force, mass, and acceleration, of work and energy, and of impulse and momentum are introduced and first applied to problems involving only particles. Thus students can familiarize themselves with the three basic methods used in dynamics and learn their respective advantages before facing the difficulties associated with the motion of rigid bodies.

Since this text is designed for a first course in statics, new concepts are presented in simple terms and every step is explained in detail. On the other hand, by discussing the broader aspects of the problems considered, a definite maturity of approach is achieved. For example, the concepts of partial constraints and of static indeterminacy are introduced early in the text and then are used throughout.

The fact that mechanics is essentially a *deductive* science based on a few fundamental principles is stressed. Derivations are presented in their logical sequence and with all the rigor warranted at this level. However, the learning process being largely *inductive,* simple applications are considered first. Thus, the statics of particles precedes the statics of rigid bodies, and problems involving internal forces are postponed until Chap. 6. Also, in Chap. 4, equilibrium problems involving only coplanar forces are considered first and are solved by ordinary algebra, while problems involving three-dimensional forces, which require the full use of vector algebra, are discussed in the second part of the chapter.

Free-body diagrams are introduced early, and their importance is emphasized throughout the text. Color has been used to distinguish forces from other elements of the free-body diagrams. This makes it easier for the students to identify the forces acting on a given particle or rigid body and to follow the discussion of sample problems and other examples given in the text. Free-body diagrams are used not only to solve equilibrium problems but also to express the equivalence of two systems of forces or, more generally, of two systems of vectors. This approach is particularly useful as a preparation for the study of the dynamics of rigid bodies. As will be shown in the volume on dynamics, by placing the emphasis on "free-body-diagram equations" rather than on the standard algebraic equations of motion, a more intuitive and more complete understanding of the fundamental principles of dynamics can be achieved.

Because of the current trend among engineers to adopt the international system of units (SI units), the SI units most frequently used in mechanics are introduced in Chap. 1 and are used throughout the text.

A large number of optional sections are included. These sections are indicated by asterisks and thus are easily distinguished from those which form the core of the basic statics course. They may be omitted without prejudice to the understanding of the rest of the text. Among the topics covered in these additional sections are the reduction of a system of forces to a wrench, applications to hydrostatics, shear and bending-moment diagrams for beams, equilibrium of cables, products of inertia and Mohr's circle, mass products of inertia and principal axes of inertia for three-dimensional bodies, and the method of virtual work. An optional section on the determination of the principal axes and moments of inertia of a body of arbitrary shape has also been included in this new edition (Sec. 9.18). The sections on beams are especially useful when the course in statics is immediately followed by a course in mechanics of materials, while the sections on the inertia properties of three-dimensional bodies are primarily intended for the students who will later study in dynamics the three-dimensional motion of rigid bodies.

The material presented in the text and most of the problems require no previous mathematical knowledge beyond algebra, trigonometry, and elementary calculus, and all the elements of vector algebra necessary to the understanding of the text are carefully presented in Chaps. 2 and 3. In general, a greater emphasis is placed on the correct understanding of the basic mathematical concepts involved than on the nimble manipulation of mathematical formulas. In this connection, it should be mentioned that the determination of the centroids of composite areas precedes the calculation of centroids by integration, thus making it possible to establish the concept of moment of area firmly before introducing the use of integration. The presentation of numerical solutions takes into account the universal use of calculators by engineering students, and instructions on the proper use of calculators for the solution of typical statics problems have been included in Chap. 2.

Each chapter begins with an introductory section setting the purpose and goals of the chapter and describing in simple terms the material to be covered and its application to the solution of engineering problems. The body of the text is divided into units, each consisting of one or several theory sections, one or several sample problems, and a large number of homework problems. Each unit corresponds to a well-defined topic and generally can be covered in one lesson. In a number of cases, however, the instructor will find it desirable to devote more than one lesson to a given topic. Each chapter ends with a review and summary of the material covered in that chapter. Marginal notes are included in these sections to help students organize their review work, and cross-references are used to help them find the portions of material requiring their special attention.

The sample problems are set up in much the same form that students will use when solving the assigned problems. They thus serve the double purpose of amplifying the text and demonstrating the type of neat and orderly work that students should cultivate in their own solutions.

A section entitled *Solving Problems on Your Own* has been added to each lesson, between the sample problems and the problems to be assigned. The purpose of these new sections is to help students organize in their own minds the preceding theory of the text and the solution methods of the sample problems so that they may more successfully solve the homework problems. Also included in these sections are specific suggestions and strategies which will enable the students to more efficiently attack any assigned problems.

Most of the problems are of a practical nature and should appeal to engineering students. They are primarily designed, however, to illustrate the material presented in the text and to help students understand the basic principles of mechanics. The problems have been grouped according to the portions of material they illustrate and have been arranged in order of increasing difficulty. Problems requiring special attention have been indicated by asterisks. Answers to 70% of the problems are given at the end of the book. Problems for which no answer is given are indicated by a number set in italic.

The inclusion in the engineering curriculum of instruction in computer programming and the widespread availability of personal computers or mainframe terminals on most campuses make it possible for engineering students to solve a number of challenging mechanics problems. At one time these problems would have been considered inappropriate for an undergraduate course because of the large number of computations their solutions require. In this new edition of *Vector Mechanics for Engineers: Statics*, a group of problems designed to be solved with a computer follow the review problems at the end of each chapter. Many of these problems are relevant to the design process; they may involve the analysis of a structure for various configurations and loadings of the structure, or the determination of the equilibrium positions of a given mechanism which may require an iterative method of solution. Developing the algorithm required to solve a given mechanics problem will benefit the students in two different ways: (1) it will help them gain a better understanding of the mechanics principles involved; (2) it will provide them with an opportunity to apply the skills acquired in their computer programming course to the solution of a meaningful engineering problem.

The authors wish to acknowledge the helpful collaboration of Professor Elliot Eisenberg to this sixth edition of *Vector Mechanics for Engineers* and thank him especially for contributing many new and challenging problems. The authors also gratefully acknowledge the many helpful comments and suggestions offered by the users of the previous editions of *Mechanics for Engineers* and of *Vector Mechanics for Engineers*.

Ferdinand P. Beer
E. Russell Johnston, Jr.

List of Symbols

a	Constant; radius; distance
$\mathbf{A}, \mathbf{B}, \mathbf{C}, \ldots$	Reactions at supports and connections
$A, B, C, \ldots$	Points
A	Area
b	Width; distance
c	Constant
C	Centroid
d	Distance
e	Base of natural logarithms
$\mathbf{F}$	Force; friction force
g	Acceleration of gravity
G	Center of gravity; constant of gravitation
h	Height; sag of cable
$\mathbf{i}, \mathbf{j}, \mathbf{k}$	Unit vectors along coordinate axes
$I, I_x, \ldots$	Moment of inertia
$\bar{I}$	Centroidal moment of inertia
$I_{xy}, \ldots$	Product of inertia
J	Polar moment of inertia
k	Spring constant
k_x, k_y, k_O	Radius of gyration
$\bar{k}$	Centroidal radius of gyration
l	Length
L	Length; span
m	Mass
$\mathbf{M}$	Couple; moment
$\mathbf{M}_O$	Moment about point O
$\mathbf{M}_O^R$	Moment resultant about point O
M	Magnitude of couple or moment; mass of earth
M_{OL}	Moment about axis OL
$\mathbf{N}$	Normal component of reaction
O	Origin of coordinates
p	Pressure
$\mathbf{P}$	Force; vector
$\mathbf{Q}$	Force; vector

$\mathbf{r}$	Position vector
r	Radius; distance; polar coordinate
$\mathbf{R}$	Resultant force; resultant vector; reaction
R	Radius of earth
$\mathbf{s}$	Position vector
s	Length of arc; length of cable
$\mathbf{S}$	Force; vector
t	Thickness
$\mathbf{T}$	Force
T	Tension
U	Work
$\mathbf{V}$	Vector product; shearing force
V	Volume; potential energy; shear
w	Load per unit length
$\mathbf{W}$, W	Weight; load
x, y, z	Rectangular coordinates; distances
$\bar{x}, \bar{y}, \bar{z}$	Rectangular coordinates of centroid or center of gravity
α, β, γ	Angles
δ	Elongation
$\delta\mathbf{r}$	Virtual displacement
δU	Virtual work
$\boldsymbol{\lambda}$	Unit vector along a line
η	Efficiency
θ	Angular coordinate; angle; polar coordinate
μ	Coefficient of friction
ρ	Density
ϕ	Angle of friction; angle

Contents

3
RIGID BODIES: EQUIVALENT SYSTEMS OF FORCES 67

4
EQUILIBRIUM OF RIGID BODIES 149

5
DISTRIBUTED FORCES: CENTROIDS AND CENTERS OF GRAVITY
204

6
ANALYSIS OF STRUCTURES
270

7
FORCES IN BEAMS AND CABLES
337