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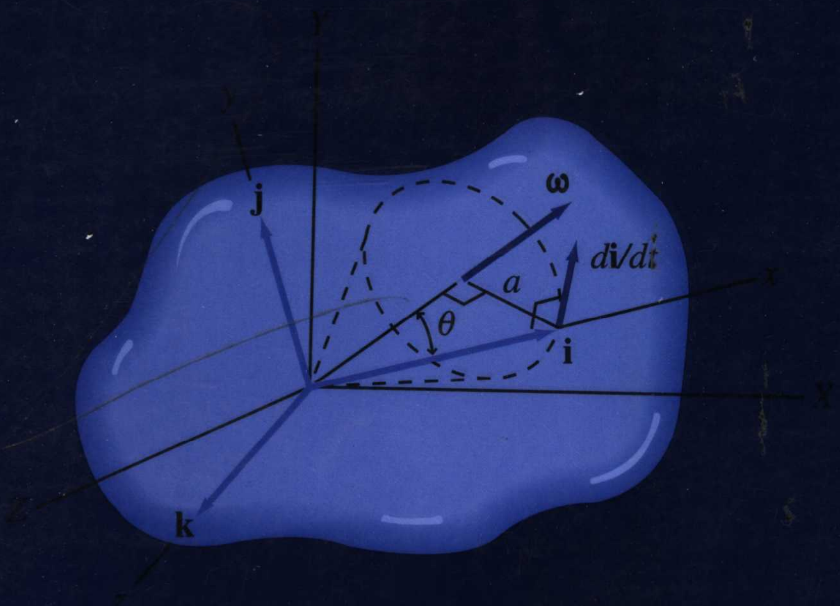
缩编国外精品教材

Engineering Mechanics

理论力学

[美] Arthur P. Boresi　Richard J. Schmidt 著
杨昌祺 杨萌 万玲 缩编



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[美]Authur P. Boresi, Richard J. Schmidt 著
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电 话: (023) 65102378 65105781
传 真: (023) 65103686 65105565
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缩编说明

本教材是 P. Boresi & Richard J. Schmidt 教授所著的"Engineering Mechanics-Statics"和"Engineering Mechanics-Dynamics"两本教材的缩编版，根据我国机械类和近机类中学时理论力学课程教学的基本要求，对原教材进行了较大幅度的压缩。为了尽量保持原教材的便于自学和联系工程实际的风格，结合我国学生的实际情况，本教材在前半部分保留了部分与物理重叠的内容，使学生逐步适应双语教学环境，在后半部分对和物理重叠的内容进行了大幅度压缩。

缩编后共 14 章，内容包括：力学概念的回顾，力与其他矢量分量，质点的平衡，平面力、力偶和刚体的平衡，空间的力、力偶和刚体的平衡，简单结构与机械，重心、质心与分布力，摩擦，动力学引论、质点运动学，质点动力学，质点的动量定理，刚体运动学，刚体动力学，动能、动量与刚体的平面运动。另附英制与国际单位制换算表和原书著者序。

缩编版教材与原教材相比，主要有以下不同：

- 缩编版教材篇幅小，不及原教材的 1/3，便于学生自学和教师组织教学。
- 删除了桁架、流体静力学、梁与轴、功能原理、振动、空间刚体动力学等章节，贴近机械类、近机类中学时理论力学教学大纲，适用于中学时理论力学课程双语教学。
- 为了保证教材风格，在缩编中采用整章节删除的方式，保留部分仅对涉及删除章节的语句进行了必要的微调。
- 原教材包含了大量的例题和习题，但为了缩减篇幅，缩编版教材只保留了部分核心例题与习题，教师可以从网络教学资源中获取更多的例题与习题。
- 为使读者对原教材风格有更全面的了解，保留了原书著者序。由于缩编教材对原书进行了较大幅度的缩编，原书著者序中关于章节的说明部分已经没有太大的实际意义，已从原书著者序中删除。

此外，缩编教材还保留了原教材的下列主要特色：

- 所有章节都保持了原著的编排风格，使学生能够按照原著者极力推崇的 SQ3R 学习-阅读方法进行学习。
- 例题与习题与工程实际紧密结合，大多数例题和习题均可找到应用背景。
- 缩编版教材中大多数内容采用国际单位制，但也有部分内容采用英制单位，为便于使用英制单位，缩编版教材保留了英制与国际单位制换算表。英制单位与我国现行的教材单位制有差别，建议在学习中加以注意。
- 本教材语言流畅，编排新颖，图文并茂，通俗易懂，联系实际，是一本适合理论力学课程双语教学的优秀教材。

杨昌棋

2005 年 7 月

***Dedicated to our children*:**
Jennifer, Annette, and Nancy
Marshall, Charles, and Catherine

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To the Instructor

Our intention in writing this book is to provide a thorough, rigorous presentation of mechanics, augmented with proven learning techniques for the benefit of instructor and student. Our first objective is to present the topics thoroughly and directly, allowing fundamental principles to emerge through applications to real-world problems. We emphasize concepts, derivations, and interpretations of the general principles, and we discuss the applicability and limitations of each principle. We illustrate that general rules frequently have exceptions; however, we do not dwell on these to the extent that they become a distraction. This book presents, in the clearest form possible, more theorems, more proofs, and more explanation than you will find in most introductory engineering mechanics texts.

Our second objective is unique. We have attempted to integrate learning principles and teaching techniques that improve students' ability to grasp and absorb concepts. In general, texts in engineering mechanics focus exclusively on the technical principles, with no structure to increase student comprehension. The integrated use of learning aids in this book is based on our experience that students can be taught effective study habits while they learn mechanics.

Each chapter in this book is organized around the SQ3R study-reading method. ① This structured approach to reading directs the student to:

- develop a global view of the course material one section or chapter at a time.
- organize the material into manageable pieces and read each piece for content and comprehension, and
- review the material as a coherent whole.

Details of the SQ3R method are described in *To the Student*, which also offers tips on note taking and presents a formal strategy for problem solving. The SQ3R method offers an integrated approach to studying mechanics that requires no additional preparation or follow-up by the instructor.

FEATURES AND DESIGN

To maximize students' success, instructors must capture their interest and attention. The instructor's task is to cultivate students' interest, while educating them in the fundamentals and broad applications of mechanics. To facilitate that task, we attempt to present mechanics in the most exciting and relevant context possible. Since the study of mechanics is not limited to engineering practice, we include examples and illustrations of mechanics at work in many different applications. For a wider perspective and a sense of tradition, we include historical references to balance the technical presentation.

Much of engineering mechanics involves the development of mathematical models of the physical world. In particular, visualization of three-dimensional physical systems and development of appropriate models are of paramount importance. We facilitate this process throughout the text by including pertinent photographs and figures emphasizing a wide range of applications from simple to complex.

Throughout the text, we integrate *Problem-Solving Techniques*. These are not step-by-step solution methods to be used mechanically by the students, but rather summaries of the key concepts

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① SQ3R is an acronym for Survey, Question, Read, Recite, and Review (Robinson, 1970).

and issues that must be considered to solve particular types of problems.

A large number of example and homework problems provide students with ample opportunities to apply concepts and principles to familiar, meaningful situations. The homework problems include relatively simple introductory problems that test students' basic understanding, as well as more challenging problems requiring a deeper grasp of concepts and techniques. They also include problems that are best solved with the aid of computerbased tools (spreadsheets, equation solvers, and plotting tools) and problems that are design-oriented. The design problems are intended to introduce students to the kinds of decisions that will be expected of them throughout their engineering studies and in professional practice and to give them an appreciation for the importance of engineering mechanics in the design process. These problems do not cover all aspects of design, but are intended to introduce students to the challenge of creating a part or a system that will perform a particular function. Icons identify these three types of homework problems:

Challenging

Computer-based

Design-oriented

Solving numerical problems alone is not sufficient to allow students to learn the fundamental concepts that underlie the equations and solution techniques used in mechanics. So, we have included in each chapter *Survey Questions*, *Checkpoints*, and *Review Questions* that challenge students' understanding of fundamental concepts. These short-answer questions, appropriate for homework assignments or examinations, help students develop a balance between understanding concepts and applying them to problem solving.

HOMEWORK PROBLEMS AND SOLUTIONS

Each homework problem in this book was solved by both the authors and students. We used student problem solvers to help us test the clarity of the problem statements, identify the relative difficulty of the problems, and obtain approximate solution times. As a result of this process, we edited or rewrote some problems. Each section of the Problems at the end of each chapter is arranged approximately in order of increasing time required to obtain the solution. The solution times are given in the Solution Manual.

We developed the solutions presented in the Solution Manual to be used by students as teaching aids after they have attempted to solve the problems. For the most part, the solutions are fairly detailed and similar in format to those presented in the text for the Examples. This approach allowed us to outline the problem-solving process, as well as give correct answers. The Preface to the Solution Manual describes more completely the process used to develop the problems and their solutions.

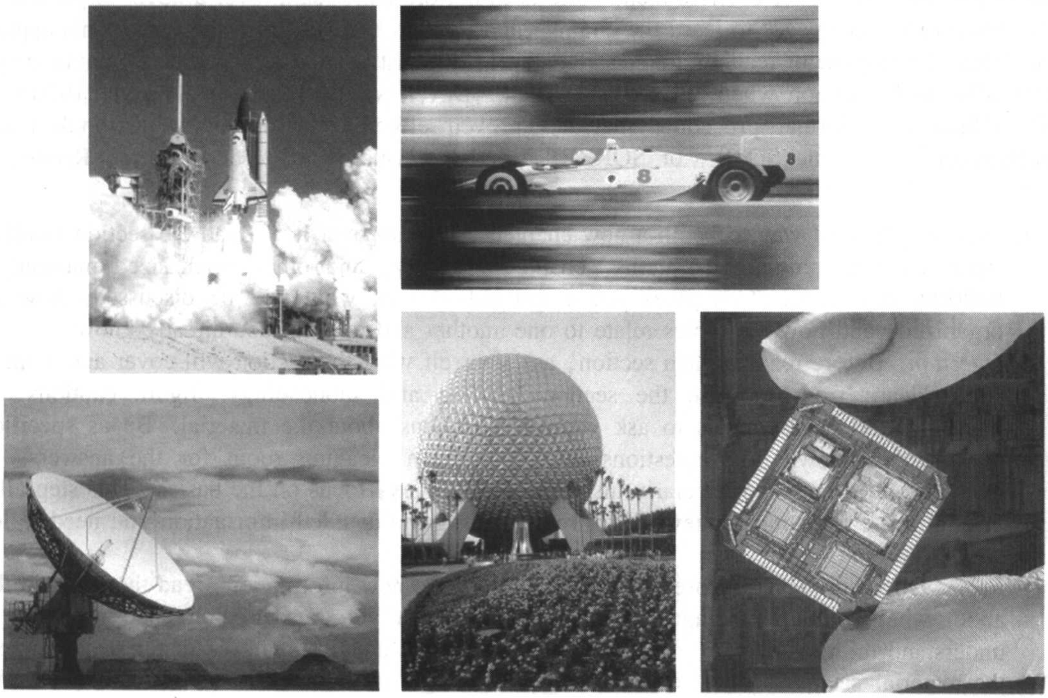
We believe that we have developed homework problems that are student-tried and student-tested, with solutions that are correct and complete. Nevertheless, we are solely responsible for any errors that exist. So, we welcome any feedback that you may wish to offer. Send corrections, comments, or suggestions for improvements to:

Arthur P. Boresi or Richard J. Schmidt
Department of Civil and Architectural Engineering
University of Wyoming
PO Box 3295
Laramie WY 82071-3295

To the Student

The purpose of this book is to start you on the road to becoming a good engineer. Although fundamentals of physics and mathematics are important in this endeavor, we emphasize applications of physical and mathematical principles to engineering. While physicists are interested primarily in understanding the principles that govern the natural world and mathematicians focus on developing mathematical models to describe natural phenomena, engineers seek to create what does not exist in nature and to enrich people's lives by solving problems that confront modern society. Indeed, an engineer is a problem solver. To be an effective engineer, you must develop a thorough understanding of physical and mathematical principles and their application to the world around you.

Statics and dynamics form the basis for a large part of your study in engineering. The importance of these fields cannot be overstated. For many of you, the study of statics and dynamics will be your first opportunity to formally apply your skills in algebra, trigonometry, and calculus and to expand your understanding of how the laws of physics apply to real-world problems.



The designs of all engineering systems—from massive space vehicles to tiny microprocessor chips—are based on the fundamental laws of mechanics.

A systematic approach facilitates the solution of problems in mechanics. Knowledge of a set of mathematical tools and techniques for solving problems is not sufficient; You must also have motivation, ingenuity, and an organized strategy for attacking new problems. Our first objective in writing this book on engineering mechanics is to present the topics in a thorough and systematic way so that fundamental principles become evident through application to real-world problems, including examples from everyday engineering practice. We emphasize concepts, derivations, and interpretations of the general principles. Our goal is to give you a clear grasp of major concepts by presenting the simplest and most elementary derivations that are consistent with the demands of rigor. Then, we apply those concepts and derivations in example problems to illustrate their use.

Our second objective is to help you develop your study skills and problem-solving abilities. These cannot always be developed intuitively, but the use of problem-solving strategies can accelerate their development. We present such strategies, which you can apply to become a more efficient problem solver.

STUDYING AND LEARNING TOOLS

Engineering is a challenging field, both as a student and as a professional. To succeed, you must develop effective study habits, adding structure and discipline to your routine. We offer the following tools designed to help you accomplish this goal.

Reading—The SQ3R Method The process of reading a textbook for understanding is not the same as that of reading a novel for entertainment. One does not ordinarily skim over a novel to get the high points, jump to the last pages to learn the ending, and then go back to fill in the gaps. This approach would defeat the purpose of reading a novel. However, it is just what you should do to maximize your understanding and retention when reading a textbook. Developed by Francis Robinson (1970), the SQ3R method is a formal procedure that has proven effective in improving textbook reading comprehension. The name SQ3R (or SQRRR) stands for Survey, Question, Read, Recite, and Review.

- *Survey*. The best way to begin a new chapter is to skim over it. ② Read the section headings, figure captions, highlighted items, chapter summary, and other emphasized material that indicates key ideas. This gives you a general idea of what will be discussed, how it is organized, and how the topics relate to one another and to what you already know.
- *Question*. Before reading each section, ask yourself what the section will cover and what you should learn from it. Use the section heading and subheadings, figure captions, and highlighted items as guides to ask yourself questions about the material. Be as specific as possible. Jot down your questions in outline form, leaving room for the answers. The questions need not be particularly insightful or complex; focus on the basics. This step allows you to create a mental framework for remembering the detailed information you need to learn while you read.
- *Read*. Once you have prepared yourself to absorb the new information, read the text and think about what you are reading. Are the questions that you raised being answered? Do you understand the relationships among the topics? Read a small amount of material at a time. If the material seems difficult or confusing, don't go on. Go back and reread the section,

② Here we use the word "chapter." However, in engineering courses, you will generally be given reading assignments that involve less than a whole chapter.

maybe just a paragraph or two at a time, until it makes sense.

- *Recite*. At the end of each section, stop. In your own words, recite the major ideas. Answer the questions on your outline. If your initial set of questions is incomplete, ask—and answer—further questions. Don't go on to the next section until you have stated the main ideas in your own words. If you cannot answer some of your questions, take them to class and discuss them with your instructor.
- *Review*. At the end of the chapter, review all of its material and your notes; then ask and answer your questions again. You should be able to see the topical relationships within each section and among the sections. Once you have grasped the main concepts, individual facts become easier to remember. It may be helpful to work with a classmate and quiz each other. Finally, combine your SQ3R notes with your lecture notes to create a coherent, well-organized package for the chapter. Then, take a break and relax. Approach each chapter with a fresh outlook.

Note Taking Taking notes during a classroom lecture is far different from being a court stenographer. A stenographer records every word spoken, but the point of note taking in class is to capture the main points accurately and in an organized way so that you can use your notes later as a study aid. Students who develop a mental outline of a lecture's main ideas and concentrate on capturing those in a few words typically remember more than students who try to write down every detail.

Here are some simple hints for effective note taking:

- Come to class prepared. Do the assigned reading before class and bring your SQ3R notes. Ask your questions when the instructor is discussing the topic that confuses you. Jot down his or her answer on your outline. Use the lecture time to fill in the gaps in your own understanding, not to provide you with your first exposure to the topic. If you prepare for the lecture ahead of time, you will already have your general outline, and you will recognize important points.
- Every day, imagine that you are taking notes for your best friend who could not attend class that day. Your objective is to give your friend an organized set of notes that record the *key points* of the lecture. Your lecture notes should be a supplement to your SQ3R notes.
- During the lecture, listen for key words that signal main ideas ("The three primary reasons that..."), an alternative explanation ("In other words, ..."), a conclusion or summary statement ("Finally, we can say that..."), or a change of direction ("On the other hand...").
- Do not assume that the instructor will write on the board everything that you are expected to know. Read everything that is written, and listen to everything that is said; but be selective in what you write down in your notes. Note taking takes concentration. Take brief notes so that you are not distracted from the lecture for long periods of time.
- After class and before the next class, combine your SQ3R notes and your lecture notes into a single, organized unit. This is another opportunity to review the material and solidify your understanding. If you missed a point or two during the lecture, leave space in your rewritten notes for additional detail. Then talk to your instructor to fill in the gaps. When the time comes for an exam, your rewritten notes will be well-organized and complete—perfect for exam preparation.

Developing Problem-Solving Skills To be an effective problem solver, you must follow an organized strategy.

- *Define the problem.* Read the given information thoroughly and carefully before working the problem. Unnecessary, incorrect, or misleading information could distract you from the real problem.
- *Think about it.* Be sure you have an accurate understanding of the problem. Don't jump into the solution process without identifying the facts and features of the problem situation. Summarize and organize what is given. Do you have enough information to solve the problem? Have you solved a similar problem before?
- *Plan your approach.* Make a flowchart outlining the solution process. Decide where to start and what sequence of steps to follow to reach the solution. Break the problem down into manageable pieces that can be solved one at a time. Think about alternate plans in case your first plan does not succeed.
- *Carry out your plan.* Persevere, and do not lose confidence in your plan.
- *Look back and evaluate.* Make sure you solved the problem that was posed. Determine whether your solution is reasonable. Does it agree with what your intuition tells you? Check all calculations for math errors, correct signs, decimal place locations, transposed digits, proper units, and so on. Be certain that your solution and the answer are presented in a readable, logical form that will not be misinterpreted. ③

CHAPTER ORGANIZATION

We have organized this book to facilitate use of the SQ3R method. Features of each chapter include the following:

- *A Look Forward* provides a general perspective on the chapter. The main topics are introduced in relatively nontechnical terms so that you can get a sense of what is important before you begin detailed study.
- *Survey Questions* are included to start you on the SQ3R method. These questions are fairly simple and are based on an overview of the contents of the chapter. You are encouraged to perform your own survey and develop additional questions.
- *Key Terms* are printed in the margins of the text as signposts to recognize during reading. On completing a chapter, you should be able to define each of its key terms.
- *Key Concepts* are highlighted statements of the chapter's main ideas that appear throughout the text. They are relatively general so that you can grasp the big picture, then fill in the details from the text discussion.
- *Learning Objectives* are specific, performance-related statements at the beginning of each section. They help you assess your learning by telling you specifically what you should know or understand after you have studied a section.
- *Checkpoints* at the ends of sections present true/false or short-answer questions that remind you to recite a section's main points. As you answer these questions, work on your chapter outline and check your survey questions. Answers are given below each Checkpoint box, but try to answer the questions before looking at them.
- *Chapter Highlights* are provided at the end of each chapter for your survey and review.
- *Problems* are grouped at the end of each chapter rather than immediately after the text and

③ In Section 1.5, we expand on these ideas and apply them explicitly to problem solving in engineering mechanics. Throughout this book, we include step-by-step strategies, called *Problem-Solving Techniques*, to help you develop your own methods of problem solving.

examples to which they relate. This organization preserves the continuity and flow of the text material and emphasizes that problem solving should follow thorough study of the chapter. However, we have divided the problems by section and have arranged the problems for each section in increasing order of difficulty. Icons next to problem numbers identify three special types of problems:

Problems that are more challenging

Problems that are best solved using computer-based tools

Problems that are design-oriented

- *Review Questions* at the end of each chapter allow you to explain the concepts in your own words. Your ability to paraphrase key concepts will help you apply them during problem solving.

FINAL WORDS

An old saying goes: "What I hear, I forget; what I see, I may remember; what I experience, I know for life." Many engineers are visual, sensory learners, relying on examples, demonstrations, and illustrations to help them generalize and understand fundamental, often abstract, concepts. For this reason, this book is illustrated with photographs and drawings to enliven and enrich your study of mechanics. Apply what you learn to your own life, and know it for life. We have done all that we can to get you off on the right foot. The rest is up to you. Now start your study of mechanics with our best wishes for your success.

Arthur P. Boresi
Richard J. Schmidt

Contents

Chapter 1
Review of Concepts In Mechanics

Renaissance scientist Galileo Galilei (1564–1642) was the first person to develop the modern quantitative description of the motion of a projectile in a vacuum.

A Look Forward

IN THIS CHAPTER, we will review some history of mechanics and certain fundamental concepts that form the foundation of modern engineering mechanics. We also outline problemsolving methods that will serve you well throughout your engineering career. Included in the discussion is the proper use of numerical calculations to ensure accuracy in engineering mechanics.

The application of mechanics principles requires the use of trigonometry, algebra, and calculus. Therefore, we advise you to refer to your mathematics textbooks to review those topics as needed. The material in this chapter is intended as reference material for use throughout the entire book. You should return to it if you have questions regarding definitions and conversions of units, accuracy of calculations, and dimensions.

Finally, you should use this book as a reference in your future courses in engineering. Statics and dynamics form the basis for much of your later coursework (and engineering practice), so you will often need to refer back to these topics to refresh your understanding.

Survey Questions

- What is mechanics? Are there subfields within mechanics?
- How old is the field of mechanics?
- Have the principles of mechanics changed substantially since the time of Newton?
- Isn't a particle just a really small body?
- What role do units of measure play in the study of mechanics?

1.1 BRIEF HISTORY OF MECHANICS

After studying this section, you should be able to:

- Define the science of mechanics and briefly outline its history.
- Identify and distinguish between systems composed of particles and those composed of rigid bodies.

Key Concepts Mechanics is the science that considers the motion of bodies under the action of forces.
Statics is the study of motionless systems or systems that move with constant velocity.

Mechanics is the science that considers the motion of bodies and the effects of forces on that motion. Mechanics includes statics, which deals with the special case of a body at rest (one that does not move) or a body that moves with constant velocity. A body at rest or moving with constant velocity is said to be in *equilibrium*.

The origins of the science of mechanics are lost in antiquity. However, many historians associate the birth of mechanics with the research of the Greek mathematician Archimedes (287–212 B.C.), who developed principles for the analysis of parallel forces and applied these principles to the statics of simple levers, systems of pulleys, floating bodies, and centers of gravity of bodies.

The successful analysis of nonparallel forces was not accomplished until nearly 2000 years after the death of Archimedes, when the Flemish mathematician and inventor Simon Stevin (1548–1620) solved the inclined plane problem (which involves nonparallel forces). Stevin also used directed line segments to represent forces and included an arrowhead on a line segment to indicate the sense of the force along the line (Fig. 1.1). He showed how to add two forces to obtain their *resultant* by constructing a force parallelogram with the forces (arrows) as the sides. The diagonal of the parallelogram then represents the sum, or resultant, of the two forces (Fig. 1.2; see also Sec. 2.3). Quantities that add like forces are called *vectors*.① The French scientist René Descartes (1596–1650) developed the idea of resolving vectors into projections parallel to *coordinate axes*.② Complementing Stevin's parallelogram law, this idea greatly facilitates computations in both two and three dimensions

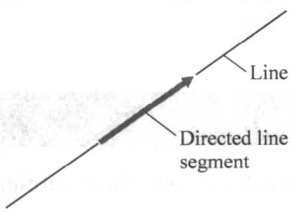


Figure 1.1 Directed line segment.

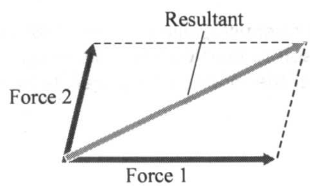


Figure 1.2 Force parallelogram.

① According to Lamb (1924), the term "vector" (or "carrier") for quantities such as force that possess both magnitude and direction was introduced by Sir W. R. Hamilton. Lamb also credits Hamilton with the first use of the term "scalar."

② The concept of Cartesian (rectangular) coordinates was first developed by Descartes.