FOURTH EDITION

Applied Mechanics for Engineering Technology

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APPLIED MECHANICS FOR ENGINEERING TECHNOLOGY

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Library of Congress Cataloging-in-Publication Data

Walker, Keith M.
Applied mechanics for engineering technology / Keith M. — 4th ed.
p. cm.
Includes text.
ISBN. 0-13-040585-X
1. Mechanics, Applied. I. Title.
TA350.W19 1991
620. 1—dc20 90-48435
CIP

Editorial/production supervision
and interior design: Merrill Peterson
Cover design: Lundgren Graphics, Ltd.
Manufacturing buyer: Ed O'Dougherty
Prepress buyer: Mary McCartney
Page layout: Judy Winthrop

Printed in the United States of America
10 9 8 7 6

ISBN 0-13-040585-X

Prentice-Hall International (UK) Limited, *London*
Prentice-Hall of Australia Pty. Limited, *Sydney*
Prentice-Hall Canada Inc., *Toronto*
Prentice-Hall Hispanoamericana, S.A., *Mexico*
Prentice-Hall of India Private Limited, *New Delhi*
Prentice-Hall of Japan, Inc., *Tokyo*
Simon & Schuster Asia Pte. Ltd., *Singapore*
Editora Prentice-Hall do Brasil, Ltda., *Rio de Janeiro*

Applied Mechanics for Engineering Technology

To my wife Judy

who gave support in many ways

Preface

Applied mechanics is more than the teaching of physics principles. It is an important instrument in developing a method of stripping a problem to essentials and solving in a logical, organized manner. This method of working can be applied to many other areas. This book, therefore, shows a consistent pattern of problem solving. The physics principles are presented in small elementary steps, the mathematics is kept at a reasonable level, and the problems are as practical as possible without becoming too involved with many extraneous details.

To accommodate the transition years between the English system and the SI metric system, each chapter is a random mix of both systems but predominantly SI metric. There are more than 160 worked examples and 850 graded problems of which nearly two-thirds are in the SI metric system.

I would now like to address the student directly. You will no doubt discover problems that defy solution, no matter how well you understand all previous examples or problems. At the end of each chapter there is a list of hints for problem solving. It is not necessarily a summary of the chapter material but is rather similar to a serviceman's troubleshooting list. It is a list of the common areas where past students have had difficulty or made errors. Hopefully by going back over your diagrams and calculations, using this checklist, you will find self-study and problem solving not only easier but certainly less frustrating.

Keith M. Walker

Contents

CHAPTER 1

Introduction

OBJECTIVES

Upon completion of this chapter the student will be able to:

1. **Explain why applied mechanics is necessary in engineering.**
2. **Submit a problem solution complete in all aspects of organized layout, units, and significant figures.**
3. **Solve for lengths or angles of a right-angle triangle using the trigonometric functions of sine, cosine, and tangent.**
4. **Apply the sine law to an appropriate triangle.**
5. **Apply the cosine law to an appropriate triangle.**
6. **Solve for lengths or angles in problems combining all previous trigonometry in addition to basic geometry principles such as opposite angle, supplementary angle, and sum of the included angles of a triangle.**

1-1 WHAT AND WHY OF APPLIED MECHANICS

To someone who has never been exposed to applied mechanics, the subject may seem on first examination to be closely akin to a formal physics course since physics is what it most closely relates to in the high-school curriculum. But applied mechanics is basically an engineering science with practical applications. In this book we do not emphasize the purely theoretical approach but endeavor to show the practical applications of new theory.

Basic mechanics is composed of two principal areas—statics and dynamics. In this book, *statics* will be dealt with first; it is the study of forces on and in structures that are at rest or moving at a uniform velocity. A motionless body may have several forces acting on it, for example, gravitational force and a force opposing that gravity. Such a body is therefore *static*, or motionless, and has forces in balance, or *equilibrium*. Statics is the analyzing and determining of such forces. *Dynamics*, which will be studied later, is the next logical step in the study of forces since it is concerned with *dynamic equilibrium*, or the forces acting on a moving body.

Applied mechanics, since it deals with the very basic concept of force, is the origin for all calculations in areas such as stress analysis, machine design, hydraulics, and structural design. The design of an aircraft landing gear would require knowledge in all of these areas.

There are reasons other than the above for learning mechanics: the discipline is invaluable in developing one's logic or reasoning ability; one also learns a method of applying a little theory in a logical, neatly organized manner to arrive at a solution to a practical problem. The key to success is the method of attacking problems rather than the learning of massive quantities of theory. For those who prefer to memorize equations and to look for a "plug into the formula" solution, a change in method will be required.

The "why" of applied mechanics is therefore twofold: to lay the groundwork of theory for future engineering calculations and to train a person to organize and present his or her work in a logical manner. Such theory and the logical thought processes that must accompany it are the groundwork for many future engineering subjects.

1-2 UNITS AND BASIC TERMS

The units in this book will be predominantly SI metric; the remainder will be the English system. A metric system was standardized in June 1966 when the International Organization for Standardization approved a metric system called *Le Système International d'Unités*. The abbreviation is SI. This supplanted the old MKS metric system.

There are some changes required in the previous metric system, but the most marked change will be for countries converting from the English system to the SI metric system. Due to the current phase of conversion to the SI system, the units used in examples and problems are mixed randomly throughout the book.

In the SI system, there are only six basic units (Table 1-1). These basic

TABLE 1-1

Physical quantity	Name	Symbol
Length	meter	m
Mass	kilogram	kg
Time	second	s
Electric current	ampere	A
Temperature	kelvin	K
Luminous intensity	candela	cd

units must measure quantities that could vary considerably in magnitude. To avoid awkwardly large or small figures, prefixes representing multiples and submultiples will be used (Table 1-2). You will notice that the multiples and submultiples are in increments of three digits. There are others that do not follow this pattern and therefore are not part of the SI system. Their use is permitted for convenience in certain cases.

TABLE 1-2

Name	Symbol	Multiply by:
	Multiples	
kilo	k	10^3
mega	M	10^6
giga	G	10^9
tera	T	10^{12}
	Submultiples	
milli	m	10^{-3}
micro	μ	10^{-6}
nano	n	10^{-9}
pico	p	10^{-12}

The multiples are

hecto	h	multiply by 10^2
deka	da	multiply by 10

The submultiples are

deci	d	multiply by 10^{-1}
centi	c	multiply by 10^{-2}

For those who may not be familiar with the metric prefixes, the following equivalent values will demonstrate their use.

$$1 \text{ kilometer} = 1000 \text{ meters}$$

$$1 \text{ km} = 1000 \text{ m}$$

$$1 \text{ millimeter} = 10^{-3} \text{ meter}$$

$$1 \text{ mm} = 10^{-3} \text{ m}$$

$$10^3 \text{ mm} = 1 \text{ m}$$

Some of the principal SI-derived units are shown in Table 1-3. The units and terms in this table will be discussed when each specific area is covered.

TABLE 1-3

Quantity	Unit	Symbol	Description
Acceleration	meter per second squared	—	m/s^2
Angle	radian	rad	—
Angular acceleration	radian per second squared	—	rad/s^2
Angular momentum	kilogram meter squared per second	—	$kg \cdot m^2/s$
Angular velocity	radian per second	—	rad/s
Area	square meter	—	m^2
Density	kilogram per cubic meter	—	kg/m^3
Energy	joule	J	N·m
Force	newton	N	$kg \cdot m/s^2$
Frequency	hertz	Hz	s^{-1}
Length	meter	m	—
Mass	kilogram	kg	—
Moment (torque)	newton-meter	—	N·m
Momentum	kilogram meter per second	—	kg·m/s
Power	watt	W	J/s
Pressure	pascal	Pa	N/m^2
Strain	—	—	mm/mm
Stress	pascal	Pa	N/m^2
Time	second	s	—
Velocity	meter per second	—	m/s
Volume			
Solids	cubic meter	—	m^3
Liquids	liter	l	10^{-3} m^3
Work	joule	J	N·m

The following discussion of each will serve as an introductory explanation and as a central reference.

Length

A base unit of 1 meter (m) is used. The popular multiples are kilometers (km) and millimeters (mm). The centimeter (cm) is used for calculations to avoid unwieldy numbers and for convenience in other cases. The predominant unit in the English system is the foot (ft). Inches (in.) and miles are also used (1 ft = 12 in.; 1 mile = 5280 ft).

Mass

The *mass* of an object is a measure of the amount of material in the object.

A base unit of 1 kilogram (kg) is used (1 tonne = 1000 kg). In the English system, it is the slug. Mass, weight, and force of gravity are discussed further under the heading "Force."

Time

The base unit of time is 1 second (s). Note that the abbreviation is "s" rather than "sec" as in the English system. Because of universal acceptance, other permitted units are minute (min), hour (h), and day (d).

Area

Area is measured in square meters (m^2) or multiples such as square millimeters (mm^2), square centimeters (cm^2), and square kilometers (km^2). Area in the English system is often in ft^2 or yd^2.

Volume

The base unit for solids is 1 cubic meter (m^3), and for liquids it is 1 liter (l), which is equal to 1 cubic decimeter (dm^3). Another common relationship between solids and liquids is 1 milliliter (ml) = 1 cubic centimeter (cm^3). The English system commonly uses ft^3 and yd^3 for solids and gallons for liquid.

Force

The unit of force is the newton (N). One newton is the force that when applied to a mass of 1 kg gives it an acceleration of 1 m/s^2 ($1 \text{ N} = 1 \text{ kg}\cdot\text{m/s}^2$). Similarly, a mass of 1 kg with the standard acceleration of gravity of 9.81 m/s^2 will have a force of gravity of $1 \times 9.81 = 9.81$ N.

In the English system, a mass of 1 slug has a weight or force of gravity = mass × acceleration of gravity = 1 slug × 32.2 ft/sec^2 = 32.2 lb. Note that in the SI system the term "weight" of an object is not usually used, but rather the force of gravity expressed in newtons. The newton is a relatively small unit of force; therefore, common multiples are kN and MN. To handle large forces in the English system, the kilopound (kip) is used (1 kip = 1000 lb).

Angle

The *radian* (rad) is used for measuring plane angles. In common practice, plane angles will continue to be measured in degrees although the use of minutes and seconds is discontinued (e.g., 38.2° rather than 38°12′). The radian is the angle between two radii of a circle that cut off on the circumference, an arc equal in length to the radius. Since the circumference = $2\pi r$, there are 2π radians in 360°.

Pressure

Pressure is force per unit area, and the derived unit used is 1 pascal = 1 newton per square meter (1 Pa = 1 N/m^2). Again, this is a relatively small unit; therefore, kPa and MPa are often used. Units of psi ($lb/in.^2$) are common in the English system.

Stress

Stress is an internal load per unit area; therefore, it is expressed in units of pascals as is pressure. The English system uses $lb/in.^2$.

Strain

Strain is a measure of length per length, and the SI system requires the use of millimeters/millimeter (mm/mm). Units of cm/cm may be encountered since they are still in common usage in some countries. The English system uses units of in./in.

Energy

The *joule* is the work done when a force of 1 newton acts through a distance of 1 meter. Since

$$\text{work} = \text{force} \times \text{distance}$$

$$1\ \text{J} = 1\ \text{N}\cdot\text{m}$$

Similar to the pascal, the joule is a relatively small unit and may often be preceded by the larger prefixes of kilo and mega. In the English system, a force of 1 pound acts through a distance of 1 foot, giving units of ft-lb.

Work

Since work is energy, it has units of joules.

Power

Power is the rate of doing work. One *watt* of power is the rate of 1 joule of work per second.

$$\text{power} = \frac{\text{work}}{\text{time}}$$

$$1\ \text{W} = 1\ \text{J/s} = 1\ \text{N}\cdot\text{m/s}$$