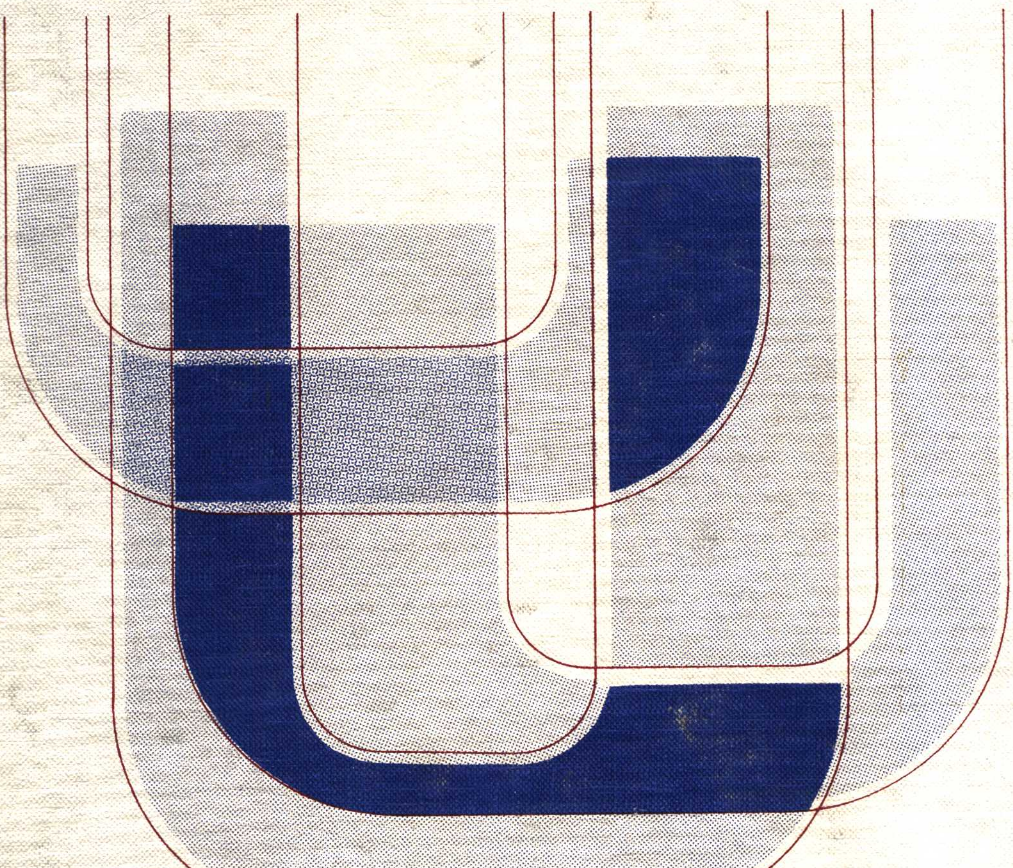
IRVING GRANET

Fluid Mechanics for Engineering Technology



SECOND EDITION

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Fluid Mechanics for Engineering Technology

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This book is dedicated to my devoted wife, Arlene, whose love and forebearance made its completion possible.

Preface

Although some time has elapsed since the first edition of the book was written, all of the objectives stated at that time are still valid. It is a *textbook* designed to be used by a student who will be studying fluid mechanics at a community college, technical institute, or in bachelor of technology programs. With this objective in mind, I have avoided use of the calculus. However, as was noted in the first edition, the instructor has the discretion to present an alternative parallel development using calculus to increase the depth of presentation where it is deemed both warranted and feasible.

The widespread adoption of the first edition has led me to retain many of the features and arrangement of the original book. However, I have carefully considered the constructive suggestions made by users of the book and have incorporated many of them in this edition. Also, during the planning of this revision it became necessary to make a decision regarding the adoption of SI units. The generally slow adoption of the SI system of units by industry in the United States requires the technician to be familiar with both the English and SI systems at this time. Therefore, equations and problems are developed in both systems throughout the book. The first chapter of the book is devoted to introducing the student to systems of units and should prove to be valuable as a familiarization and as an introduction to the use of dimensional consistency in problem solving. The text contains over 500 problems, with complete solutions given for 134 of the problems as an integral part of the text.

Miss Cheryl Gorgoni, Mrs. Mae Shuman, and Mrs. Muriel Smith typed most of the manuscript and I am most grateful for their help in this undertaking. Professor Donald H. Wright of Suffolk County Community College reviewed the preliminary manuscript in detail making many suggestions which were subsequently incorporated into the final version. His efforts are greatly appreciated. I am also indebted to the many users of the book who took the time to make constructive suggestions. My colleagues at Queensborough Community College and New York Institute of Technology were most supportive of me during this time. My wife Arlene and our children, Ellen, Kenny, David, and Jeffrey, provided the love, patience, and understanding that made the successful completion of this undertaking possible.

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Systems of Units and Dimensional Consistency

1.1 INTRODUCTION

Fluid mechanics is the study of the behavior of fluids whether they are at rest or in motion; the study of fluids at rest is best known as *fluid statics* and the study of fluids in motion is termed *fluid dynamics*. In this book we use the term *fluid* to refer to both gases and liquids. To distinguish between a liquid and a gas, we note that while both will occupy the container in which they are placed, a liquid presents a free surface if it does not completely fill the container, but a gas will always fill the volume of the container in which it is placed. For gases it is important to take into account the change in volume that occurs when either the pressure or the temperature is changed, whereas in most cases it is possible to neglect the change in volume of a liquid when there is a change in pressure.

It is apparent that almost every part of our lives and the technology of modern life involves some dependence on and knowledge of the science of fluid mechanics. Whether we consider the flow of blood in the minute blood vessels of the human body or the motion of an aircraft or missile at speeds exceeding the velocity of sound, we need to utilize some branch of fluid mechanics to describe the motion. The literature of this subject is so vast that a brief description cannot adequately reflect its scope. At one time the subject was treated from a purely mathematical approach by one group of investigators and from an entirely empirical experimental approach by another group of investigators. In this text we use the modern technique of coordinating both approaches by supplementing theory with experiment.

Since all measurements as well as theoretical developments must explicitly state the units being used, we start our study with a discussion of systems of units.

1.2 THE SI SYSTEM OF UNITS

At the time of the French Revolution, the systems of weights and measures used throughout the world were an incoherent and almost hopeless jumble. International trade and the interchange of scientific information both suffered greatly because of this condition. French scientists and scholars of this era developed a rational system of weights and measures called the *metric system*, which was adopted by most countries of the world. In 1960, the General Conference of Weights and Measures extensively revised and simplified the older metric system and gave it the French title, *Système International d'Unités* (International System of Units), commonly abbreviated *SI*. The latest revisions and additions were made in an international conference in 1971, and work still continues on these standards.

For the engineer, the greatest confusion has been the units for mass and weight. The literature abounds with units such as slugs, pounds mass, pound force, poundal, kilogram force, kilogram mass, dyne, and so on. In the SI system, the base unit for *mass* (not weight or force) is the kilogram, which is equal to the mass of the international standard kilogram located at the International Bureau of Weights and Measures. It is used to specify the quantity of matter in a body. The mass of a body never varies, and it is independent of gravitational force.

The SI *derived* unit for force is the newton (N). The unit of force is defined from *Newton's second law of motion*: force is equal to mass times acceleration ($F = ma$). By this definition, 1 newton applied to a mass of 1 kilogram gives the mass an acceleration of 1 metre per second squared ($N = kg \cdot m/s^2$). The newton is used in all combinations of units that include force: pressure or stress (N/m^2), energy ($N \cdot m$), power ($N \cdot m/s = W$), and so on. By this procedure, the unit of force is not related to gravity as was the older kilogram force.

Weight is defined as a measure of gravitational force acting on a material object at a specified location. Thus, a constant mass has an approximate constant weight on the surface of the earth. The agreed standard value (standard acceleration) of gravity is 9.806 650 m/s². Figure 1.1 illustrates the difference between mass (kilogram) and force (newton).

The term "mass" or "unit mass" should be used only to indicate the quantity of matter in an object. The old practice of using weight in such cases should be avoided in engineering and scientific practice. The general relation that ties together mass (m) and weight (W) is

$$W = m \times g$$

where g is the local acceleration of gravity. In SI units, $g = 9.806\ \text{m/s}^2$.

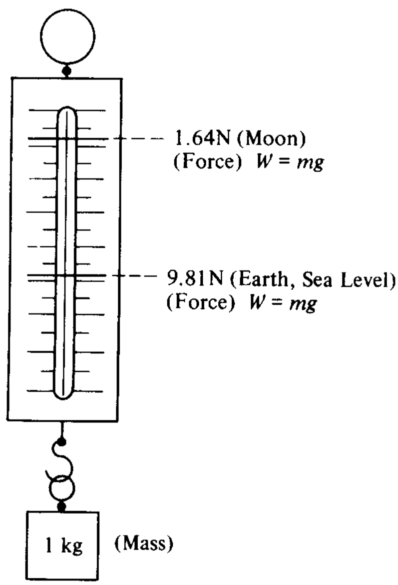

FIGURE 1.1 Mass and force.

ILLUSTRATIVE PROBLEM 1.1

One kilogram of lead is taken to the moon, where the local acceleration of gravity is one-sixth that of earth gravity. What is its mass on the moon, and how much does it weigh on the moon?

Solution

As shown in Figure 1.1, the body weighs 9.81 N on the earth. On the moon the mass will still be 1 kg, since the amount of matter in the body stays constant. However, since the local acceleration of gravity on the moon is one-sixth of the earth's gravity, it will weigh one-sixth of its earth's weight on the moon. Therefore,

$$\text{weight (moon)} = \tfrac{1}{6} \times 9.81 = 1.635\ \text{N}$$

The SI system consists of three classes of units:

1. Base units
2. Supplementary units
3. Derived units
   (a) With special names
   (b) Without special names

Table 1.1 gives the seven base units of the SI system. Several observations concerning this table should be noted. The unit of length is the metre (not meter), and the kilogram is a unit of mass, not weight. Also, symbols are never pluralized; never written with a period; and the use of upper- and lower-case symbols *must* be used as shown *without exception.*

TABLE 1.1 Base SI Units

Quantity	Name of Base SI Unit	Symbol
length	metre	m
mass	kilogram	kg
time	second	s
electric current	ampere	A
thermodynamic temperature	kelvin	K
amount of substance	mole	mol
luminous intensity	candela	cd

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Table 1.2 gives the supplementary units of the SI system. These units can be regarded as either base units or as derived units.

Table 1.3 gives the derived units (with and without symbols) often used in fluid mechanics. These derived units are formed by the algebraic combination of base and supplementary units. It is noted that where the name is named for a person, the first letter of the symbol appears as a capital (e.g.,

TABLE 1.2 Supplementary SI Units

Quantity	Supplementary SI Unit	Symbol
plane angle	radian	rad
solid angle	steradian	sr

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TABLE 1.3 Derived SI Units

Quantity	Name	Symbol	Formula	Expressed in Terms of Base Units
acceleration	acceleration	m/s^2	m/s^2	m/s^2
area	square metre	m^2	m^2	m^2
density	kilogram per cubic metre	—	kg/m^3	$kg \cdot m^{-3}$
energy or work	joule	J	$N \cdot m$	$m^2 \cdot kg \cdot s^{-2}$
force	newton	N	$m \cdot kg \cdot s^{-2}$	$m \cdot kg \cdot s^{-2}$
length	metre	m	m	m
mass	kilogram	kg	kg	kg
moment	newton-metre	$N \cdot m$	$N \cdot m$	$m^2 \cdot kg \cdot s^{-2}$
moment of inertia of area	—	m^4	m^4	m^4
plane angle	radian	rad	rad	rad
power	watt	W	J/s	$m^2 \cdot kg \cdot s^{-3}$
pressure or stress	pascal	Pa	N/m^2	$N \cdot m^{-2}$
rotational frequency	revolutions per second	rev. per sec.	s^{-1}	s^{-1}
temperature	degree celsius	°C	°C	1 °C = 1 K
time	second	s	s	s
torque (see moment)	newton-metre	$N \cdot m$	$N \cdot m$	$m^2 \cdot kg \cdot s^{-2}$
velocity (speed)	metre per second	metre per sec.	m/s	$m \cdot s^{-1}$
volume	cubic metre	—	m^3	m^3

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newton is N). Otherwise, the convention is to make the symbol lower-case.

In order for the SI system to be universally understood, it is most important that the symbols for the SI units and the conventions governing their use be strictly adhered to. Care should be taken to use the correct case for symbols, units, and their multiples (e.g., K for kelvin, k for kilo; m for milli, M for mega). As noted earlier, unit *names* are never capitalized except at the beginning of a sentence. SI unit *symbols* derived from proper names are written with the first letter in upper-case; all other symbols are written in lower-case. For example, m (metre), s (second), K (kelvin), Wb (weber). Also, unit names form their plurals in the usual manner. Unit symbols are always written in singular form: for example, 350 megapascals, or 350 MPa; 50 milligrams, or 50 mg. Since the unit symbols are standardized, the symbols should always be used in preference to the unit names. An exception is made when a number written out in words precedes the unit (e.g., seven metres, not seven m). Unit symbols are not followed by a period unless they occur at the end of a sentence and the numerical value associated with a symbol should be separated from that symbol by a space (e.g., 1.81 mm, *not* 1.81mm). The period is only to be used as a decimal marker. Since the comma is used by some countries as a decimal marker, the SI system does not use the comma. A space is used to separate large numbers in groups of threes starting from the decimal in either direction. Thus, 3 807 747.0 and 0.030 704 254 indicate this type of grouping. Notice that for numerical values of less than 1, the decimal point is preceded by a zero. For a number of four digits, the space can be omitted.

In addition, certain style rules should also be adhered to:

1. When a product is to be indicated, use a space between unit names (e.g., newton metre).
2. When a quotient is indicated, use the word "per" (e.g., metre per second).
3. When a product is indicated, use the word "square," "cubic," and so on (e.g., square metre).
4. In designating the product of units, use a centered dot (e.g., $N \cdot s$, $kg \cdot m$).
5. For quotients, use a solidus (/) or a negative exponent (e.g., m/s or $m \cdot s^{-1}$). The solidus (/) should not be repeated in the same expression unless ambiguity is avoided by using parentheses. Thus, one should use m/s^2 or $m \cdot s^{-2}$ but *not* m/s/s; also, use $m \cdot kg/(s^3 \cdot A)$ or $m \cdot kg \cdot s^{-3} \cdot A^{-1}$ but *not* $m \cdot kg/s^3/A$.

One of the features of the older metric system and the current SI system that is most useful is the fact that multiples and submultiples of the units are in terms of factors of 10. Thus, the prefixes given in Table 1.4 are used in conjunction with SI units to form names and symbols of multiples of SI units. Certain general rules apply to the use of these prefixes: