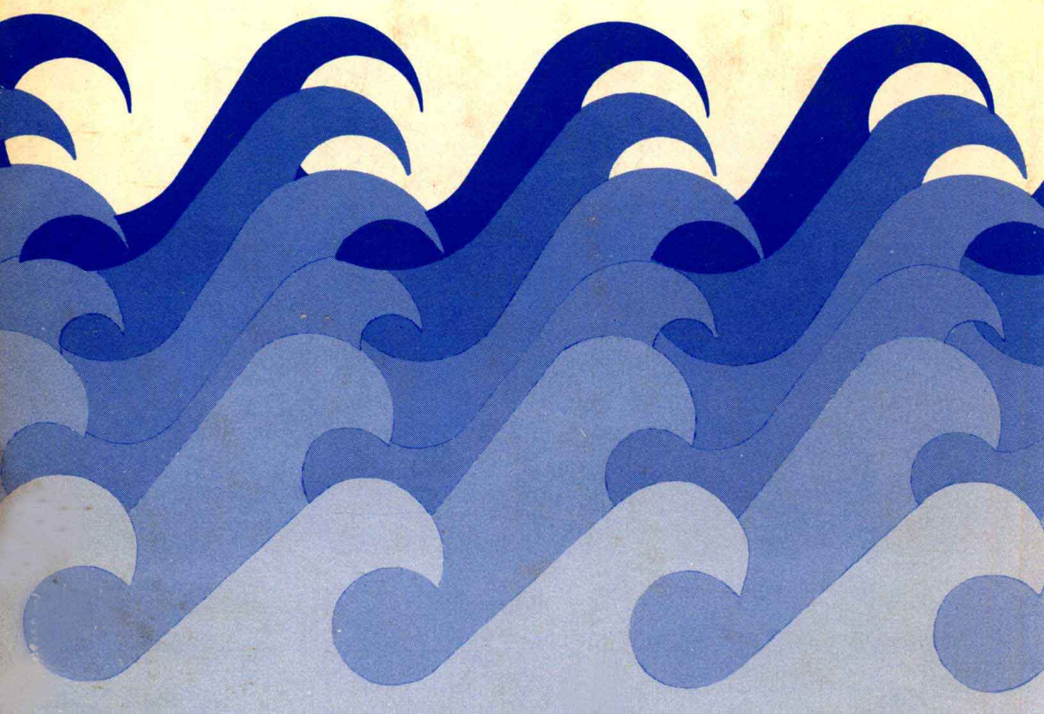
FLUID MECHANICS FOR TECHNICIANS

Thomas B. Hardison



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PREFACE

This book has two primary purposes. One is to integrate the engineering theory of fluid mechanics with the down-to-earth practical world of fluid power. The second purpose is to make the theory and its applications understandable and palatable to the typical student in a two-year engineering technology curriculum. The book has, therefore, been written for technical institute and community college use.

Those portions of fluid mechanics theory which have applications primarily in fluid power have been used in developing the text. However, conventional fluid mechanics theory relating to static and flow systems of fluids has also been incorporated. Parts relating to the older civil engineering hydraulics concept and to aerodynamics have not been included.

Calculus is not used in the book. However, the student will benefit if he has had some calculus, and it is assumed that he is proficient with algebra and trigonometry. Courses in physics also will be helpful in the course.

SI metrics have been incorporated to an extent which appears compatible with present day usage. While SI metrics will undoubtedly be used more in the future, several manufacturers have indicated that their primary use of metrics is in the area of component and part dimensional characteristics.

The latter part of the book is devoted to the applications in fluid power. While most of these applications were furnished by fluid power manufacturers and other industry sources, some are from the author's own industrial experience of 18 years. Primary components are discussed and their functioning explained to the extent that space allows.

It is hoped that the student will obtain understanding and some degree of knowledge of the field by using this text.

THOMAS B. HARDISON

LIST OF SYMBOLS AND ABBREVIATIONS

This list of standard symbols and abbreviations has been included here for easy access by the student. The following symbols and abbreviations are used throughout the text.

SYMBOL OR ABBREVIATION	*MEANING*
a	Acceleration
A	Area
°C	Temperature in degrees Celsius
d	Distance or diameter
Delta (Δ)	Change in ....
Epsilon (ϵ)	Absolute roughness
f	Friction factor
F	Force or flow factor
°F	Temperature in degrees Fahrenheit
g	Acceleration of gravity
G	Weight flow rate (lb per sec)
h	Head or height
k	Constant of proportionality
K	Temperature in degrees kelvin
lb/in.^{2} & psi	Pressure–pounds per sq in.
L	Length
m	Molecular weight
M	Mass
Mu (μ)	Absolute viscosity
n	Exponent for adiabatic and polytropic processes
N_R	Reynolds number
Omega (ω)	Angular velocity

SYMBOL OR ABBREVIATION	*MEANING*
psia	Lb per sq in. absolute-pressure
psig	lb per sq in. gage-pressure
P	Pressure
P_f	Pressure drop
Q	Volume rate of flow
R	Gas constant in ft lb/lb °R
°R	Temperature in degrees Rankine
Rho (ρ)	Density
S_g	Specific gravity
SSU	Saybolt Seconds Universal—viscosity
t	Time
Tau (τ)	Shear stress in viscosity
T	Temperature
Upsilon (υ)	Kinematic viscosity
u	Relative velocity
U	Velocity—used in viscosity
v	Velocity
V	Volume
V_s	Specific volume
W	Weight
W_s	Specific weight
Y	Distance—used in viscosity
$>$	Symbol meaning "greater than"
$<$	Symbol meaning "less than"

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chapter one

PROPERTIES OF COMPRESSIBLE AND INCOMPRESSIBLE FLUIDS

1-1 INTRODUCTION

Fluid mechanics can be described as a branch of applied mechanics that deals with the study of fluids, their properties, and their behavior. This text is primarily concerned with those aspects of fluid mechanics that lend themselves to use most frequently in industry. Some examples of applications of fluid mechanics are the shop compressed-air system, which exists in most plants; the hydraulic lift at the automobile service station; the vacuum chuck, which you will find on some machine tools; the hydraulically operated landing gear used on many aircraft; and the hydraulic shock absorber used on automobiles.

Industry has given the name *fluid power* to the field of practical application of fluid mechanics. Although it is the purpose of this text to introduce the reader to fluid power, it is equally important that you understand basic theory so that you may know how fluid mechanics is correctly applied to a specific job.

Physics deals with such terms as work, horsepower, force, velocity, energy, and friction. We shall also use these terms in fluid mechanics; in some cases they may be used in a somewhat different manner, but the basic meaning of the term remains the same.

1-2 FLUIDS

As differentiated from a solid, we can define a *fluid* as a substance (or a state of matter) that has mass but no definite shape. Since a fluid has no definite shape, it will take the shape of the vessel in which it is contained. We also have to go a step further and note the difference between liquid and gaseous fluids.

Fluids that are liquid under the conditions of use are said to be theoretically *incompressible*. Fluids that are gaseous under the conditions of use are *compressible*. Note that we restricted this definition so that the condition of the fluid is always considered; we do this because substances may change their state of matter under different temperature and pressure conditions. Water is a liquid at room temperature, a solid (ice) below freezing temperature, and above 212° F and at atmospheric pressure it is gaseous (steam). Another difference between liquids and gases is that, at a constant temperature, the volume of a liquid will not change, even though the vessel is changed; in a closed vessel, the gas volume will change so as to equal the volume of the vessel.

An ideal fluid is defined as one that has no resistance to flow. Since resistance to flow is also termed *viscosity*, the ideal fluid would have zero viscosity. In our study of fluid mechanics we will find that fluids do possess viscosity of sufficient magnitude that it cannot be neglected. Actually, most fluids behave similarly to the ideal fluids but not exactly like the ideal fluids. There are ways to compensate for this departure from the theoretical behavior, which we will go into later.

1-3 DEFINITIONS OF FLUID PROPERTIES

The important properties of fluids that apply to both liquids and gases are defined in this chapter. We shall cover separately those properties which pertain only to liquids and those which pertain only to gases.

Mass: "The property of a body which determines the effect of a force applied to it"[1]; or "a quantity of matter."[2]

We determine mass by measuring the weight of the object or the matter in question, but the mass is the weight divided by the acceleration

[1] David Halliday and Robert Resnick, *Physics* (New York: John Wiley & Sons, Inc., 1960), p. 70.

[2] *Handbook of Chemistry and Physics*, 49th ed. (Cleveland: The Chemical Rubber Co., 1968), p. 85.

of gravity:

$$M = \frac{W}{g} \tag{1-1}$$

where M = mass
W = weight
g = acceleration of gravity = 32.2 ft/s^2 in the English system of units and 9.81 m/s^2 in the SI (metric) system.

Specific weight: The weight per unit volume; for example, the specific weight of water for ordinary temperature variations is 62.4 lb/ft^3.

Density: The mass per unit volume.

$$\rho = \frac{M}{V} \tag{1-2}$$

where ρ (rho) = density; may be referred to as mass density
M = mass
V = volume

Specific volume: Mathematically, the reciprocal of the specific weight.

$$V_s = \frac{1}{W_s} \tag{1-3}$$

where V_s = specific volume
W_s = specific weight

Specific gravity: The ratio of the weight or mass of any fluid to that of an equal volume of a substance taken as a standard; in the cases of liquids and solids, water is the standard at a temperature of 4° Celsius.[3]

In the case of gases, air free of carbon dioxide and hydrogen is frequently used as the standard; in practice, we rarely use the term to pertain to anything other than liquids or solids. In this case, then, mathematically the specific gravity is

$$S_g = \frac{W_{\text{substance}}}{W_{\text{water}}} \tag{1-4}$$

where S_g = specific gravity
$W_{\text{substance}}$ = specific weight of substance
W_{water} = specific weight of water

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[3]The Celsius temperature scale was previously called centigrade.

In the SI system specific gravity may be obtained using the density of water. At 4° Celsius this is 1000 kg/m^3. Thus, the specific gravity of a substance is equal to its density divided by 1000. For example, a fluid that has a density of 1320 kg/m^3 has a specific gravity of 1.32. Older metric systems, such as the CGS (centimeter-gram-second) system, defined density on a g/cm^3 basis. Water has a density of 1 g/cm^3 in this system.

1-4 SYSTEMS OF UNITS

Two systems of units are in use throughout the world. Most industrial countries have standardized on the *International System of Units* (SI), or *metric system*. In the United States the *English system of units* is used predominantly, but there is increasing use of the SI system. Consequently, we shall use both the English and the SI system in this text. A conversion table for changing from one system to the other will be found in Table II of the Appendix.

Some metric terms still in common use in fluid mechanics are from the older CGS system. Examples are the poise and the stoke, used in the description of viscosity. Because these terms are still widely accepted, they will be used here and their SI equivalent terms listed also.

1-5 MASS, SPECIFIC WEIGHT, AND DENSITY

Practically speaking, the *mass* of a substance is a property that we can determine by weighing it and then dividing the weight by the constant of acceleration of gravity. In the English system, the unit of mass is called the *slug* and is obtained as follows: Using W in pounds and g in ft/s^2,

$$M = \frac{\text{lb}}{\text{ft/s}^2} = \frac{\text{lb s}^2}{\text{ft}}$$

The units of the slug are thus: lb s^2/ft.

In the SI system, the standard unit of mass is the *kilogram*. Since kilogram is the primary definition of mass in the metric system, it does not reduce to units of force, length, and time as does the slug in the English system.

One of our definitions of mass stated that it was the property of a body that determines the effect of a force applied to it. In physics, one of the basic laws is that force is equal to mass multiplied by acceleration, or $F = Ma$. The mass of any fluid is also subject to this relationship, just as is any mechanical object.

The relation of specific weight and density to weight are described