HANNAH & HILLIER

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Preface to third metric edition

The first edition of *Applied Mechanics* was published over thirty years ago; the first metric edition was introduced in 1971 when the system of SI units (Système International d'Unités) was adopted as the primary system of weights and measures. Since my co-author, Mr M. J. Hillier, was no longer collaborating on the writing I carried out the revision for the third metric edition myself.

The aim, as in the past, has been to retain the original character of the book, with its emphasis on the practical applications of the subject, the implications for design and the importance of the many assumptions that have to be made in engineering analysis.

Key points in the treatment remain: the number of formulae to be memorized is kept to a minimum; each topic is followed by worked examples and a list of problems for practice; purely mathematical derivations such as the moments of inertia are omitted and only results stated; work likely to have been covered in preceding courses is omitted or revised briefly, including centres of gravity, uniform velocity and acceleration; topics such as friction, properties of materials and real fluids, the nature of experimental and graphical work, and dynamics of aircraft are covered in more detail than is usual at this level.

In this edition, the text, worked examples and problems have been thoroughly revised and the diagrams redrawn. In particular, the work on aircraft, rockets and helicopters has been expanded. Although this material is intended only as an introduction to these topics there is an advantage in bringing together in the exercises the principles of statics and dynamics of forces as well as those of thermodynamics, gas dynamics and fluid flows. Some descriptive work on propulsion systems and aerodynamics has been included to support the elementary mechanics. The coverage of gravitation and satellites in the appendix to Chapter 9 has been increased; to contain the size of the book Chapter 20 (Fluid in motion) and Chapter 21 (Experimental errors and the adjustment of data) have been slightly curtailed.

The text covers all the requirements of the units of study for the BTEC certificate and diploma courses in Engineering, and some of the aspects of the new work-related advanced GNVQ courses. It is hoped also that the book will continue to be useful as a supporting text to students on the early stages of higher diploma and degree courses and on comparable courses overseas.

I am indebted to the users of the book in many parts of the world and to those in industry, engineering and other institutions who have helped with information and advice. My particular thanks are due to my colleague of many years' standing Mr R. C. Stephens, for his most valuable and ever-ready assistance with this edition.

1994

John Hannah

Note on SI units

SI is the abbreviation, in all languages, for the full title 'Système International d'Unités', which is the rationalized form of the metric system of units agreed internationally. Of the seven fundamental or **base** units, four will be met with in this book, i.e. the *metre* (length), *second* (time), *kilogram* (mass), *kelvin* (temperature).

The sole **derived** unit for measuring work or energy is the *joule* and that for force is the *newton*. The SI is a coherent system of units since the product of any two unit quantities in the system is the unit of the resultant quantity. For example, unit velocity (metre per second) results when unit length (metre) is divided by unit time (second). Normally calculations in the text are carried out by converting all given quantities to these base units, but on occasion it has been found convenient to work in multiple or sub-multiple units. The kilojoule and kilonewton are particularly convenient. A few non-SI units whose use is accepted have been used where appropriate, for example, the *bar* (and its multiples) as a unit of pressure and the *knot*, a unit of speed, in aerial and marine navigation work.

For full information on SI units reference should be made to *SI International System of Units*, R. J. Bell and D. T. Goldman (National Physical Laboratory), published by H.M. Stationery Office (1986), and to British Standards No. 5555 and No. 350 Part I.

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Chapter 1

Statics

Statics is the study of forces on bodies *at rest* or in *steady motion*. The student at this stage should already be familiar with the elementary principles and theorems relating to forces in equilibrium and the following notes are intended as revision, but with an emphasis on the application of these principles to engineering problems.

1.1 Mass, force and weight

The *mass* of a body is the quantity of matter it contains.

A *force* is simply a push or a pull and may be measured by its effect on a body. A force may change or tend to change the shape or size of a body; if applied to a body at rest the force will move or tend to move it; if applied to a body already moving the force will change the motion.

A particular force is that due to the effect of gravity on a body, i.e. the *weight* of a body.

These three quantities – mass, force and weight – are dealt with fully in Chapter 5, but it is necessary here to specify the units and the essential relationship between mass and weight.

The base SI unit of mass is the *kilogram* (kg); other units of mass are:

$$\begin{aligned} 1 \textit{ megagram} \text{ (Mg) or } \textit{tonne} \text{ (t)} &= 10^3 \text{ kg} \\ 1 \textit{ gram} &= 10^{-3} \text{ kg} \\ 1 \textit{ milligram} \text{ (mg)} &= 10^{-6} \text{ kg} \end{aligned}$$

The derived SI unit of force is the *newton* (N) defined as *that force which, when applied to a body having a mass of one kilogram, gives it an acceleration of one metre per second squared*. From Newton's second law of motion (*see* page 81) we have

$$\text{force} = \text{mass} \times \text{acceleration}$$

i.e. $$F = ma$$

where F is the applied force, m the mass of a body and a the acceleration produced in the body. Thus, in SI units, $F = 1$ N, $m = 1$ kg and $a = 1$ m/s^2,

i.e. $1(\text{N}) = 1(\text{kg}) \times 1(\text{m/s}^2)$

Other units of force used are:

$$1\ \textit{kilonewton}\ (\text{kN}) = 10^3\ \text{N}$$
$$1\ \textit{meganewton}\ (\text{MN}) = 10^6\ \text{N}$$
$$1\ \textit{giganewton}\ (\text{GN}) = 10^9\ \text{N}$$

The acceleration of any body towards earth in free fall is $g = 9.8\ \text{m/s}^2$, hence the weight W of a body of mass m is:

force = mass × acceleration

i.e. $W = mg$

If the mass m is in kilograms, then

$$W = m \times 9.8\ \text{N}$$

If the mass m is in megagrams (tonnes), then

$$W = m \times 1000 \times 9.8\ \text{N}$$
$$= m \times 9.8\ \text{kN}$$

(Figure 5.5, Chapter 5, shows the relationship between the weight W of a body and its mass m.)

Although defined in dynamic terms, a force may also be measured statically by the weight of the mass it will just support or by comparing its effect with the weight of a standard mass. Thus, if a mass m is suspended from a spring (Fig. 1.1) the extension is due to the force of gravity on the mass, i.e. to its weight $W = mg$. If y is the extension produced by this force W and a force F on the same spring produces an extension x then the value of F is measured in terms of W by simple proportion: thus

$$\frac{F}{W} = \frac{x}{y}$$

Proper specification of a force requires knowledge of three quantities:

- its magnitude
- its point of application
- its line of action

Since a force has magnitude, direction and sense, it is a *vector quantity* and may be represented by a straight line of definite length and direction.

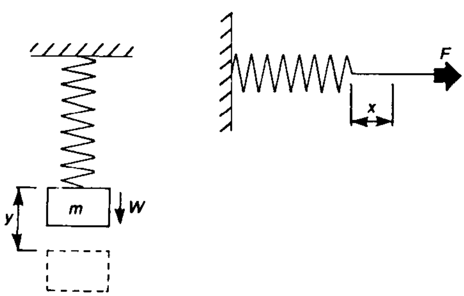

Fig. 1.1

Dead loads
In statics the vertically downward force due to the weight of 'dead loads' must always be taken into account, and this force of gravity acts through the centre of gravity of the load. In a structure such as a bridge, the dead load is the weight of the bridge framework itself plus the cladding and rail track or road surface. (Note that a train travelling over the bridge is a 'live' load.) A load may be given in force units, i.e. N, kN, MN or GN. A 'load' may also be specified in mass units, i.e. kg or Mg (tonne), and in this case the corresponding *weight* of the mass must be found before carrying out calculations involving forces.

1.2 Forces in equilibrium: triangle of forces

Statics is the study of forces *in equilibrium* ('in balance'). A single force cannot exist alone and is unbalanced. For equilibrium it must be balanced by an equal and opposite force acting along the same straight line. Thus in Fig. 1.2 the load of 1 kN *on* the tie is balanced at the joint O by an equal and opposite force of 1 kN exerted *by* the joint *on* the tie. Thus forces may be said to exist in pairs. Nevertheless, a single force may also be balanced by any number of other forces.

For three forces in the same plane to be in equilibrium:

- They must have their lines of action all passing through one point, i.e. they must be *concurrent*.
- They may be represented in magnitude and direction by the three sides of a triangle *taken in order*, i.e. by a *triangle of forces*.

The condition that all three forces must pass through one point is particularly useful in solving mechanics problems. For example, the light jib crane shown in Fig. 1.3(a) is in equilibrium under the action of three forces. The jib carries a load W at A; the free end is supported by a cable in which the tension is T; the end C is pinned to the wall by a joint which allows free rotation of the jib at C. The reaction F of the joint on the jib is completely unknown; the magnitude of T is unknown but its direction must be that of the cable. Since the three forces are in balance their lines of action must pass through one point, i.e. where the lines of action of W and T intersect (point Z, Fig. 1.3(a)). The line of action of F is therefore found by joining C to Z.

Since the magnitude of W is known and the directions of the three forces have been determined, the triangle of forces can now be drawn, Fig. 1.3(b). The sense of the forces T and F are determined by taking the sides of the triangle *in order*, i.e. by

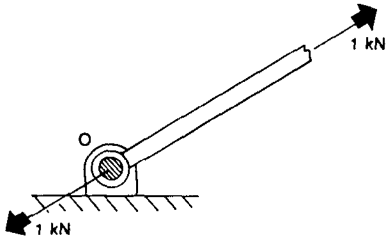

Fig. 1.2