Introduction to Mechanical Engineering Science

A solid foundation of sound engineering principles, analysis and technical problem-solving skills.

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First Edition

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I am indebted to my wife for her love, understanding and support throughout the time of writing this textbook.

Bolakale Aremu

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Preface to First Edition

Approach and Content

This textbook is intended for students who are in the first or second year of a typical college or university program in mechanical engineering or a closely related field. Throughout the following chapters, I have attempted to balance the treatments of technical problem-solving skills, engineering principles and analysis with numerous worked examples. Practice exercises are also included for you to test your understanding of each topic treated in the book.

The book begins with scalar and vector quantities in Chapter 1. In Chapter 2 you will study dynamics. You will learn rectilinear motion of particles, basic equations of motion, displacement, speed, velocity, acceleration, torque, Newton's laws of

Purpose

Over the past decade, many colleges and universities have taken a fresh look at their engineering curricula with the objective of positioning engineering content earlier in their programs, particularly for the freshman year. This textbook will introduce first-year and second-year students to the ever-emerging field of mechanical engineering and help them appreciate how engineers analyze and solve technical problems.

As the title implies, this textbook is neither an encyclopedia nor a comprehensive treatment of the discipline. Such a task is impossible for an introductory textbook like this, and, regardless, my perspective is that the traditional four-year engineering curriculum is just one of many steps taken during a lifelong education.

By studying this textbook, fresh students will learn the principles and find their way in the "forest" of mechanical engineering by examining a few of its "trees". Along the way, they will learn with clear diagrams and worked examples, some interesting and practical elements of mechanical engineering.

This textbook reflects my experiences and philosophy for introducing fresh engineering students to the vocabulary, skills, applications, and excitement of the mechanical engineering discipline.

motion, principles of conservation of energy, momentum and different types of forces. You will also be introduced to the concept of work, energy and power.

In Chapter 3, we will return to statics. We will look at moments and frictional forces. You will learn the laws of Friction, friction on an inclined plane, tractive resistance, and application of friction to brakes and bearings. In Chapter 4, we will move on to circular motion. You will learn about motion in a circle and centripetal force with worked examples.

In Chapter 5, you will study mechanical oscillations. You will learn simple harmonic motion, damped oscillation, forced oscillation and resonance. the principles of machine, such as mechanical advantage, velocity ratio (speed ratio) and efficiency. You will learn with several worked examples application of machines, such as the inclined plane, screw jack, wheel and axle, transmission of pressure in hydraulic press, gear trains, the worm wheel, belt tension and belt slip.

In Chapter 6, we will look at the principles of machine, such as mechanical advantage, velocity ratio (speed ratio) and efficiency. You will learn with worked examples application of machines, such as the inclined plane, screw jack, wheel and axle, transmission of pressure in hydraulic press, gear trains, the worm wheel, belt tension and belt slip.

Chapter 7 is all about fluid at rest. We will look at pressure at a depth, pressure measuring instruments, atmospheric pressure, pressure gauges, surface tension and Archimedes' principle with worked examples. Chapters 8 is dedicated to fluid dynamics. We will look at properties of fluid such as density, viscosity, turbulent flow, Bernoulli's equation and momentum of fluid with worked examples.

In Chapter 9, you will study energy and its uses, and different sources of energy, such as solar, wind. water and biofuels. You will also learn about thermal power station, hydroelectric power station, and so on.

In Chapter 10, we will look at a few more complex worked examples that cover all the topics discussed in the previous chapters. This will give you more problem-

solving and analytical skills. Furthermore, you will learn some of the calculations and estimates or approximations that mechanical engineers can perform as they solve technical problems and communicate their results. For mechanical engineers to accomplish their jobs better and faster, they combine science, mathematics, computer-aided engineering tools, hands-on skills and experience.

Finally, after studying this book, you will not be an expert in mechanical engineering. That is not my intention of writing this book, and it should not be yours for reading it. If my objective has been met, however, you will set in place a solid foundation of problem-solving and analytical skills, which just might form the basis for your own future contributions to the mechanical engineering profession.

About the Author

Bolakale Aremu is a mechanical engineer. He is a certified Mechanical Design Expert with 10 years of product design and development experience. Over the course of his career, he has designed, procured, and built industrial machines, medical devices and systems, optical systems, consumer products, and more. He is well versed in design for manufacturing, with a strong specialty for plastic injection molded part design.

1. Statics

1.1 Introduction to Mechanics

Mechanics is concerned with the relationships between forces, matter and motion among physical objects. If the forces acting on a body balance, the body is said to be **in equilibrium** and the branch of mechanics which deals with such cases is called **statics** - the subject reviewed in this chapter. In the second chapter we will consider the effects of forces which are not in equilibrium - a study known as **dynamics.**

Many engineering problems, such as designing buildings, bridges, roads, reservoirs, jet engines and aircraft, require the application of the principles of mechanics so that structures with the necessary strength are obtained using the minimum of material.

Scalar and Vector Quantities

A quantity like mass or length has magnitude or size. For example, you can say the mass of an object is 10kg or its length is 5cm. However, quantities like velocity and force have both magnitude and direction. For example, the velocity of a moving object may be 5m/s in the north direction, and a force of magnitude 10N may be acting vertically downwards. Therefore, mass and length are called scalar quantities while velocity and force are vector quantities.

Scalar quantities are therefore quantities with only magnitude while vector quantities are those with both magnitude and direction. Vector quantities are combined or added by a special rule, unlike scalar quantities which can be added according to the usual rules of arithmetic. For example, a length of 5cm added to that of 8cm makes 13cm but a velocity of 5km/h combined with a velocity of 8km/h does not necessarily make a velocity of 13km/h because the direction of motion should be considered.

1.1.1 Representation of Vectors

Consider the motion of a vehicle traveling at the speed of 50km/h in the North-East direction as shown in Figure 1.1.1a.

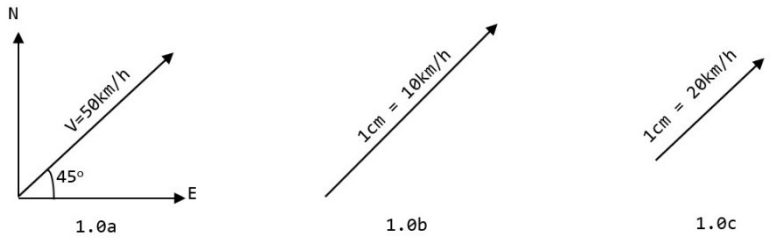

Figure 1.1.1: Representation of a vector V by both magnitude and direction. The scales that can be used are depicted in 1.0b and 1.0c.

If the motion is to be represented vectorially as shown in Figure 1.1.1b and Figure 1.1.1c, it should be in such a way that the length of the line is

1. a scale multiple of its magnitude, i.e., if a scale of lcm to 10km/h is used then the length of a line representing 50km/h will be 5cm, and 2.5cm if the scale is lcm to 20km/h.

2. parallel to the direction of motion i.e., at angle 45° to the horizontal.

A vector can always be written either as a single letter **u** (in bold black) or as either AB or $\underline{AB}$. In the second representation, the direction of the vector is clearly stated, i.e., from A to B as shown in Figure 1.1.2.

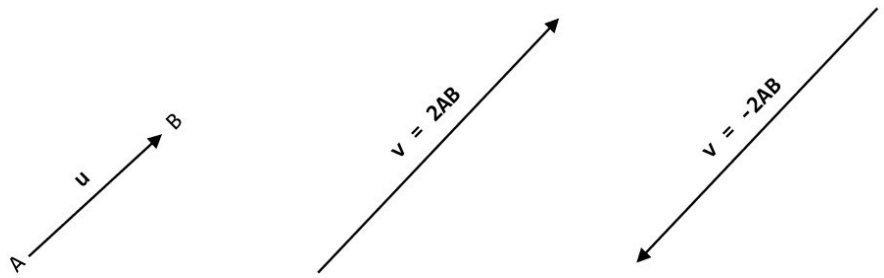

Figure 1.1.2: Three ways of representing vectors.

A vector **v** can have scalar multiples such as 2AB, i.e., twice the magnitude of vector AB, and in the same direction as AB. A negative scalar multiple like -2AB reverse the direction of the vector.

1.2 Addition and Subtraction of Vectors

For vectors in the same direction, the addition operation can be done arithmetically, which means you can add them the way you would add scalars. For example, in Figure 1.2.1,

AC= AB + BC.

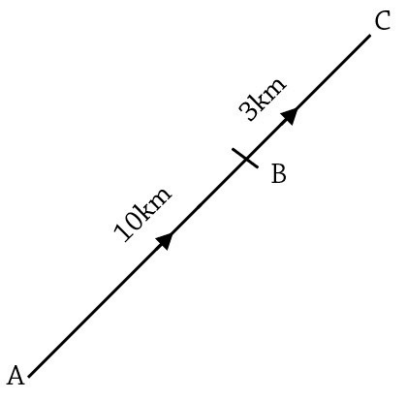

Figure 1.2.1: Adding two vectors AB and BC acting in the same direction.

In other words, since the two vectors are parallel, a displacement of 10km in the

direction of A to B added to a displacement of 3km in the same direction of B to C produces a resultant or is equivalent to a displacement of 13km in the direction of A to C.

However, if the vectors are not in the same direction, then, the **parallelogram law of vector addition** now holds. This law states that…

If two vectors acting at a point are represented in magnitude and direction by the adjacent sides of a parallelogram, then their resultant is represented in magnitude and direction by the diagonal of the parallelogram drawn from the common point.

Consider two vectors **a** and **b** (OA and OB respectively) shown in Figure 1.2.2a.

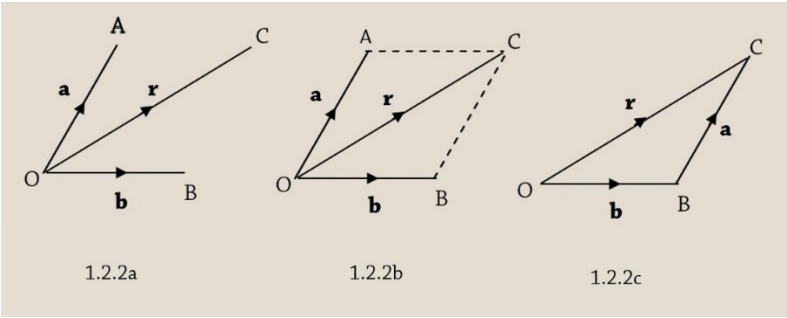

Figure 1.2.2: How to add two vectors OA and OB together using the parallelogram law of vector addition.

To draw a parallelogram for the two vectors in Figure 1.2.2a, follow these steps to arrive at the result shown in Figure 1.2.2b:

1. Draw line AC (shown dotted) parallel to and equal in magnitude to line OB.

2. Draw line BC (shown dotted) parallel to and equal in magnitude to line OA.

3. The diagonal of the parallelogram so formed is the **resultant** of the forces (vectors) OA and OB.

As shown in Figure 1.2.2c where the dotted lines and line OA have been removed, the resultant **r** or OC is the longest side of triangle OBC. So, $\mathbf{r} = \mathbf{a} + \mathbf{b}$.

Note: All drawings must be to scale.

You can subtract one vector from another. For example, if you want to obtain the resultant of **a** – **b**, you can get it by following the same steps outlined above. All you have to do is reverse the direction of **b** but its magnitude must be the same. See Figure 1.2.3a. To apply the parallelogram law of vector addition, move vector OB horizontally to the left.

Form a parallelogram with the two vectors **a** and **-b** as shown in Figure 1.2.3b. The resultant r is the diagonal BC of the parallelogram you just formed. Replace line OC with BA since they are parallel. You now have the triangle illustrated in Figure 1.2.3c, where you can measure or calculate the resultant **r**.

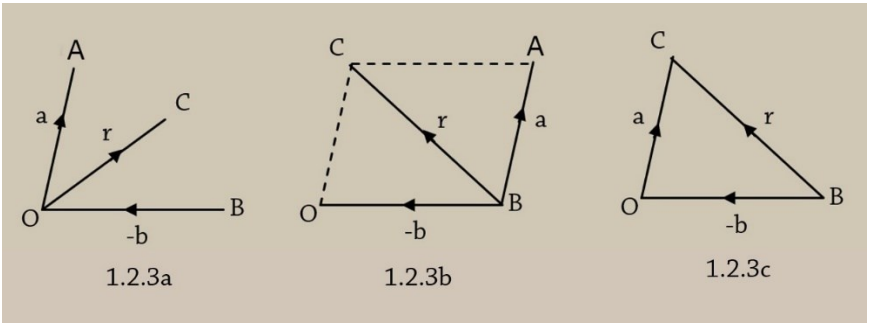

Figure 1.2.3: How to subtract vector OB from vector OA using the parallelogram law of vector addition.

1.3 Resolution of Vectors

Even if a vector such as force is neither acting in a vertical nor horizontal direction, it still has "representatives" known as components in these two directions.

Therefore, by resolution of a vector we mean the splitting of a single vector into two or more vectors acting in different directions, which would together produce the same effect as the single vector itself. The vectors that are formed after splitting the single vector are called **component vectors**.

In this section, trigonometry functions are very helpful. For a right-angled triangle, we have

$$\sin\theta = \frac{\text{opposite}}{\text{hypotenuse}}$$

$$\cos\theta = \frac{\text{adjacent}}{\text{Hypotenuse}}$$

$$\tan\theta = \frac{\text{opposite}}{\text{adjacent}}$$

Let us take an example of a force of 5N acting at an angle of 30° to the horizontal, as shown in Figure 1.3.1.

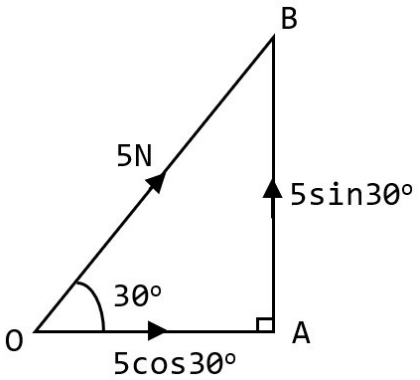

Figure 1.3.1: How to resolve a 5N force into horizontal and vertical components.

The effect of the 5N force on the vertical can be found by solving the right-angled triangle OAB and finding the value of AB, which is

AB = 5Sin30° = 5 × 0.5 = 2.50N.

Similarly, its effect or component in the horizontal direction, which is

OA = 5Cos30° = 5 × 0.8660 = 4.33N.

END OF SAMPLE

Table of Contents of Complete Book

3. Congrats and Next Steps

Congratulations! You have now successfully completed this Introduction to Mechanical Engineering guide. I hope you enjoyed it and find great satisfaction using the knowledge in your school, the workplace or elsewhere.

To continue your learning beyond this course, check out the following guides written by the same author. They are available at all major online book retailers:

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4. How to Get Further Help

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