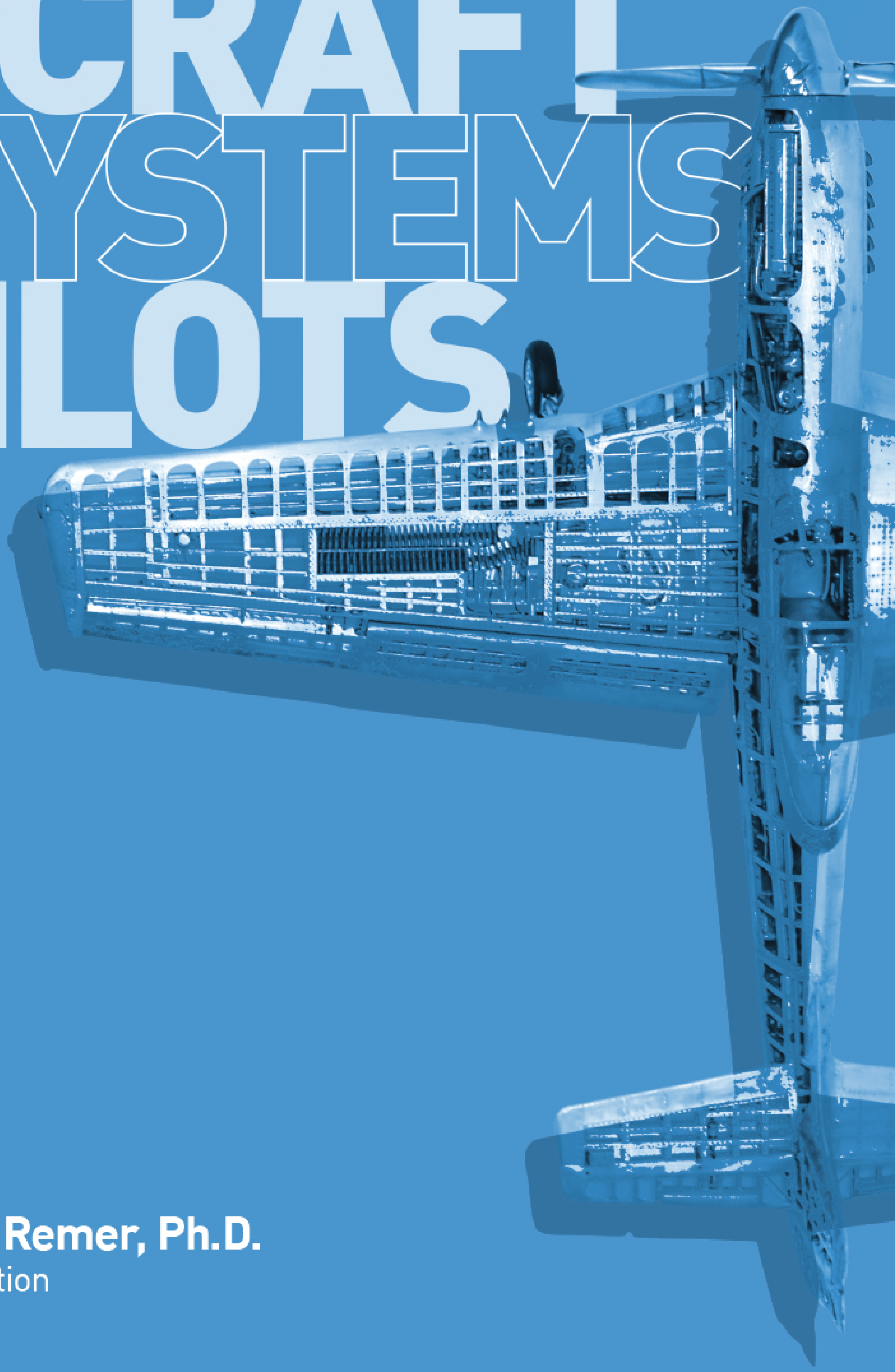
AIRCRAFT SYSTEMS for PILOTS



Dale De Remer, Ph.D.

Fourth Edition

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AVIATION SUPPLIES & ACADEMICS, INC.
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Aircraft Systems for Pilots
Fourth Edition
by Dale De Remer

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Introduction

This is not a book of new knowledge. It is, rather, an arrangement of existing knowledge from many sources into a concise presentation of what pilots should know about basic aircraft systems, based on my experiences over thirty-five years of flying and fourteen years of teaching Aircraft Systems to university students.

This text includes a brief study of the fundamentals of physical matter (from which airplanes are made) and mechanics (how airplane parts act and react) and sufficient study of each type of system which, when understood, will allow the professional pilot to stay abreast of the learning which must occur as the pilot advances into management of more and more complex aircraft.

How To Use This Textbook

Bold words have been chosen to call the reader's attention to their importance. When you read a bold word, be alert because the word will be defined or described within the sentence OR it has been so defined earlier OR shortly will be defined.

Bold Words:

1. Are about to be defined or described—be alert for this.
2. Are important to the pilot's knowledge base—learn them!
3. Are very important to the meaning of the sentence. If they are not defined, they are considered to be common knowledge. If you don't know the word and can't find it defined nearby in the text, seek its meaning in the classroom or from other books.
4. If you run across a word you don't know that isn't bold, stop and consult your dictionary. It is the only way you will be able to fully understand the sentence you have just read and besides, this is how we all build our vocabulary.

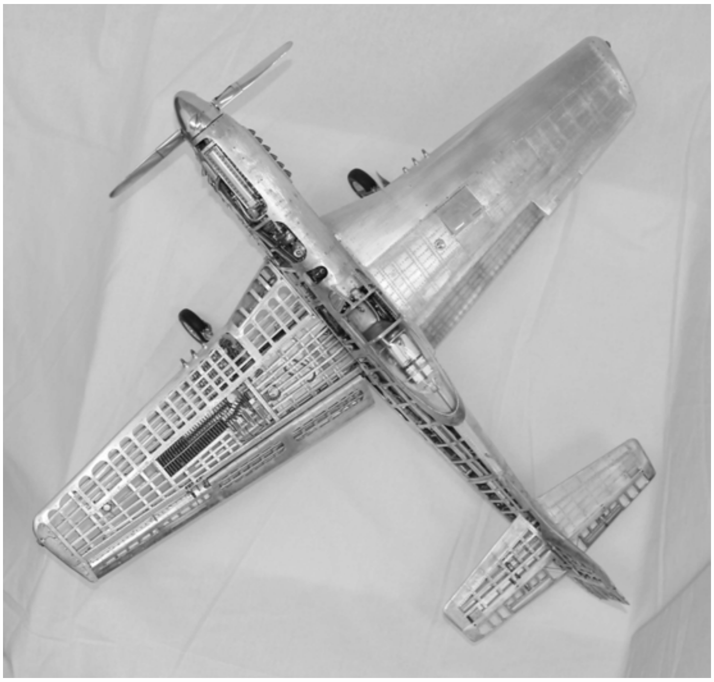
Insofar as possible, publishing standards (abbreviations, etc.) follow those of the publications manual of the APA as it is a standard that is widely accepted by aviation programs in higher education.

This book is designed to permit the student to self-learn. To utilize your instructor most efficiently, learn the assignment BEFORE coming to class. Use the study questions, as one method, to see how well you have understood what you have studied. Make notes or questions on what you don't understand so you can get further explanation and clarification from your instructor. This way, the instructor won't need to use valuable class time to teach you what you can learn on your own. In the class time saved, your instructor can take you "beyond the book." By this means, even more can be learned in the time available. Remember—it's YOUR class time!

For the pilot who is not involved in a formal study program, welcome to another opportunity to have fun—learning more about airplanes! I hope you enjoy the adventure.

Acknowledgements

The author wishes to thank the administration, faculty and staff of the Center for Aerospace Sciences for providing the environment and encouragement during the long process of researching and writing this book. Special thanks go to Mr. Greg Wagner, Assistant Professor of Aviation, for his assistance in proofing many of the chapters; Dr. Duane Cole, Professor of Physics, UND, for his assistance with Chapter One; David Blumkin for his critique of Chapter Nine; Mr. Mike Miller, IA for his proofreading efforts; and Mr. Jeff Boerboon for his contribution about preflight inspection in Chapter Sixteen. Also, many thanks to Dale Hurst and the staff at IAP, Inc., as well as Becky See, for the skill and professionalism that made completion of this book a very pleasant experience.



Cover photo: The Joe Martin Foundation for Exceptional Craftsmanship and the Miniature Engineering Craftsmanship Museum for providing the picture of the Young Park P-51 Mustang model depicted on the cover. Young Park, a retired dentist, lived in Hawaii and was an aircraft modeler since childhood. He had a lifelong dream of making an aluminum airplane model resulting in several beautifully crafted $^{1}/_{16}$ scale models that can be seen at the Miniature Engineering Craftsmanship Museum in Carlsbad, California. For more information about Young Park or to learn more about the foundation's museum, visit their website at www.craftsmanshipmuseum.com.

Chapter I
Physics

General Characteristics Of Matter

Physics is the term applied to that area of knowledge regarding the basic and fundamental nature of matter and energy. It does not attempt to determine why matter and energy behave as they do in their relation to physical phenomena, but rather how they behave.

The persons who fly, maintain and repair aircraft should have a knowledge of basic physics in order to be able to understand the interactions of matter and energy.

This may be a review for those who have a background in physics. I suggest you read it anyway. You may find the aircraft applications interesting!

Matter

Although matter is the most basic of all things related to the field of physics and the material world, it is the hardest to define. Since it cannot be rigidly defined, this chapter will point out those characteristics which are easily recognizable.

Matter itself cannot be destroyed, but it can be changed from one state into another state by chemical or physical means. Matter is often considered in terms of the energy it contains, absorbs, or gives off. Under certain controlled conditions, it can be made to aid man in the process of flight.

Matter is any substance that occupies space and has mass. There are **four states** of matter: (1) **Solids,** (2) **liquids,** (3) **gases**, and (4) **plasma**. **Solids** have a definite volume and a definite shape; **liquids** have a definite volume, but they take the shape of the containing vessel; gases have neither a definite volume nor a definite shape. Gases not only take the shape of the containing vessel, but they expand and fill the vessel, no matter what its volume. **Plasma** is made up of very hot, ionized gases. The gases are so hot that thermal collisions dissociate all of the atoms into positive ions and electrons. Most of the matter in the universe is plasma. The Sun and all the stars are giant balls of plasma. About 99% of the total mass of the universe is in this plasma state.

Water is a good example of matter changing from one state to another. At high temperature it is in the gaseous state known as steam. At moderate temperatures it is a liquid, and at low temperatures it becomes ice, a solid state. In this example, the temperature is the dominant factor in determining the state that the substance assumes. **Pressure** is another important factor that will effect changes in the state of matter. At pressures lower than atmospheric, water will boil and thus change into steam at temperatures lower than 212° F (100° C). For example, the vapor pressure of water at 98.6° F (37° C) is equal to atmospheric pressure at about 63,000 feet. This means that blood will boil at that pressure altitude! Pressure is a critical factor in changing some gases to liquids or solids. Normally, when pressure and chilling are both applied to a gas, it assumes a liquid state. Liquid air, which is a mixture of oxygen and nitrogen, is produced in this manner.

All matter has certain characteristics or general properties. These properties are defined elementally and broadly at this point, and more specifically in applications throughout the text. Among these properties and relationships are:

a. **Volume**—meaning to occupy space; having some measurements such as length, width, and height. It may be measured in cubic inches, cubic centimeters, liters, or the like.

b. **Inertia** is the characteristic of matter that resists change in motion (velocity and direction). Newton's first law is sometimes called the law of inertia: "A body at rest will remain at rest and a body in motion will continue in motion with a constant speed along a straight line path (constant velocity) unless acted upon by some net force".

c. **Mass** is a measure of the inertia of a body, and therefore is a measure of the quantity of matter associated with the body. Units for measuring mass are usually considered fundamental units for a measurement system. The gram and kilogram are units for measuring mass in the metric system of measurement and the corresponding English unit for measuring mass is the less familiar unit called the **slug.**

	METRIC SYSTEM	ENGLISH SYSTEM	EQUIVALENTS
	METER	FOOT	
LENGTH (DISTANCE)	1 CENTIMETER = 10 MILLIMETERS	1 FOOT = 12 INCHES	1 INCH = 2.54 CENTIMETERS
	1 DECIMETER = 10 CENTIMETERS	1 YARD = 3 FEET	1 FOOT = 30.5 CENTIMETERS
	1 METER = 100 CENTIMETERS	1 STATUTE MILE = 5,280 FEET	1 METER = 39.37 INCHES
	1 KILOMETER = 1000 METERS	1 NAUTICAL MILE = 6,080.27 FEET	1 KILOMETER = 0.62 MILE (ST.)
WEIGHT (MASS)	GRAM	POUND	
	1 GRAM = 1000 MILLIGRAMS	1 POUND = 16 OUNCES	1 POUND = 453.6 GRAMS
	1 KILOGRAM = 1000 GRAMS	1 TON = 2,000 POUNDS	1 KILOGRAM = 2.2 POUNDS
VOLUME	LITER	GALLON	
	1 LITER = 1000 MILLILITERS	1 GALLON = 4 QUARTS	1 LITER = .26417 GALLONS (U.S.)
	1 MILLILITER = 1 CUBIC CENTIMETER	1 QUART = 2 PINTS	1 LITER = .21998 GALLONS (BR.)
TIME	SECOND	SECOND	
	SAME AS FOR ENGLISH SYSTEM	1 SECOND = $\frac{1}{86,400}$ of average solar day.	TIME SAME FOR BOTH SYSTEMS

Figure 1-1. Comparison of metric and English systems of measurement.

d. **Gravitation**, sometimes called **mass attraction**, is a **force** that results from the characteristic of particles of matter that causes attraction or pull on other particles of matter. This mutual attraction of the mass of particles can be described in terms of gravitational forces with Newton's law of universal gravitation. Gravitational forces, like all other forces (pulls and pushes), are measured with the English unit of the **pound** or the metric unit of the **Newton**.

e. **Weight** is the name commonly used for the gravitational force of attraction betweeen the Earth and a body (mass) near the Earth. Weight is a force and is described with force units such as the pound or Newton. Since the weight of a body (gravitational force acting on the mass of the body) is proportional to the mass of the body, these different physical quantities, weight and mass, are sometimes confused.

f. **Density** is a quantity which is useful when describing matter, especially when in the liquid or gaseous state. Depending upon the application, density can be defined as either **weight density** (weight per unit volume) or as **mass density** (mass per unit volume).

Systems Of Measurement

The two most commonly used systems of measurement are the English system, which is still in general use in the United States, and the metric system, used in most European countries and now adopted by the Armed Forces of the United States. The metric system is normally used in all scientific applications.

The metric system is sometimes called the **cgs** system because it uses as basic measuring units, the centimeter (c) to measure length, the gram (g) to measure mass, and the second (s) to measure time. The metric system is also referred to as the **mks** system (meter, kilogram, second).

The English system uses different units for the measurement of mass and length. The pound is the unit of weight; the foot and inch are used to measure length. The second is used to measure time as in the metric system.

The units of one system can be converted to units in the other system by using a conversion factor or by referring to a chart similar to that shown in figure 1-1. In this figure the English and the metric systems are compared; in addition, a column of equivalents is included which can be used to convert units from one system to the other.

Fluids

Because both liquids and gases flow freely, they are called fluids, from the Latin word "fluidus," meaning to flow. A **fluid** is defined as a substance which changes its shape easily and takes the shape of its container. This applies to both liquids and gases. The characteristics of liquids and gases may be grouped under similarities and differences.

Similar characteristics are as follows:

1. Each has no definite shape but conforms to the shape of the container.
2. Both readily transmit pressures.

Differential characteristics are as follows:

1. Gases fill their containers completely, but liquids may not.
2. Gases are lighter than equal volumes of liquids.
3. Gases are highly compressible, but liquids are essentially not compressible.

These differences are described in the appropriate areas of the following discussion concerning the properties and characteristics of fluids at rest. Also included are some of the factors which affect fluids in different situations.

Machines

General

Ordinarily, a machine is thought of as a complex device, such as an internal-combustion engine or a typewriter. These are machines, but so is a hammer, a screwdriver, or a wheel. A **machine** is any device with which **work** may be accomplished. Machines are used to transform energy, as in the case of a generator transforming mechanical energy into electrical energy. Machines are used to transfer energy from one place to another, as in the examples of the connecting rods, crankshaft, and reduction gears transferring energy from an aircraft's cylinder to its propeller.

A main purpose of machines is to multiply force; for example, a system of pulleys may be used to lift a heavy load. The pulley system enables the load to be raised by exerting a force which is smaller than the weight of the load.

Machines are also used to multiply speed. A good example is the bicycle, by which speed can be gained by exerting a greater force.

Finally, machines can be used to change the direction of a force. An example of this use is the flag hoist. A downward force on one side of the rope exerts an upward force on the other side, raising the flag toward the top of the pole.

There are only six simple machines. They are the lever, the pulley, the wheel and axle, the inclined plane, the screw, and the gear. However, physicists recognize only two basic principles in machines; namely, the lever and the inclined plane. The wheel and axle, the block and tackle, and gears may be considered levers. The wedge and the screw use the principle of the inclined plane.

An understanding of the principles of simple machines provides a necessary foundation for the study of compound machines, which are combinations of two or more simple machines.

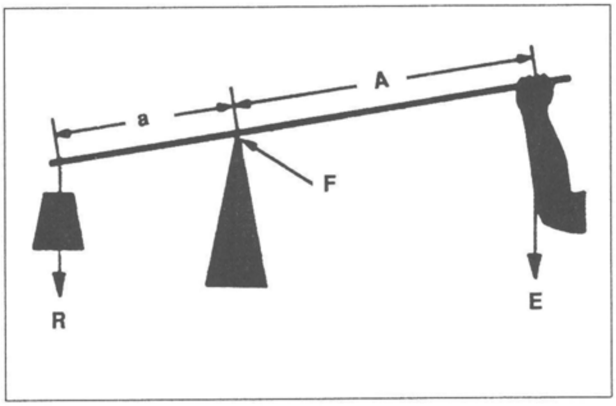


Figure 1-2. A simple lever.

The Lever

The simplest machine, and perhaps the most familiar one, is the lever. A seesaw is a familiar example of a lever in which one weight balances the other.

There are three basic parts in all levers; namely, the fulcrum "F," a force or effort "E," and a resistance "R." Shown in figure 1-2 are the pivotal point "F" (fulcrum); the effort "E," which is applied at a distance "A" from the fulcrum; and a resistance "R," which acts at a distance "a" from the fulcrum. Distances "A" and "a" are the lever arms.

Classes of Levers

The three classes of levers are illustrated in figure 1-3. The location of the fulcrum (the fixed or pivot point) with relation to the resistance (or weight) and the effort determines the lever class.

First-Class Levers

In the first-class lever (A of figure 1-3), the fulcrum is located between the effort and the resistance. As mentioned earlier, the seesaw is a good example of the first-class lever. The amount of weight and the distance from the fulcrum can be varied to suit the need.

Second-Class Levers

The second-class lever (B of figure 1-3) has the fulcrum at one end; the effort is applied at the other end. The resistance is somewhere between these points. The wheelbarrow is a good example of a second-class lever.

Both first- and second-class levers are commonly used to help in overcoming big resistances with a relatively small effort.

Third-Class Levers

There are occasions when it is desirable to speed up the movement of the resistance even though a large amount of effort must be used. Levers that

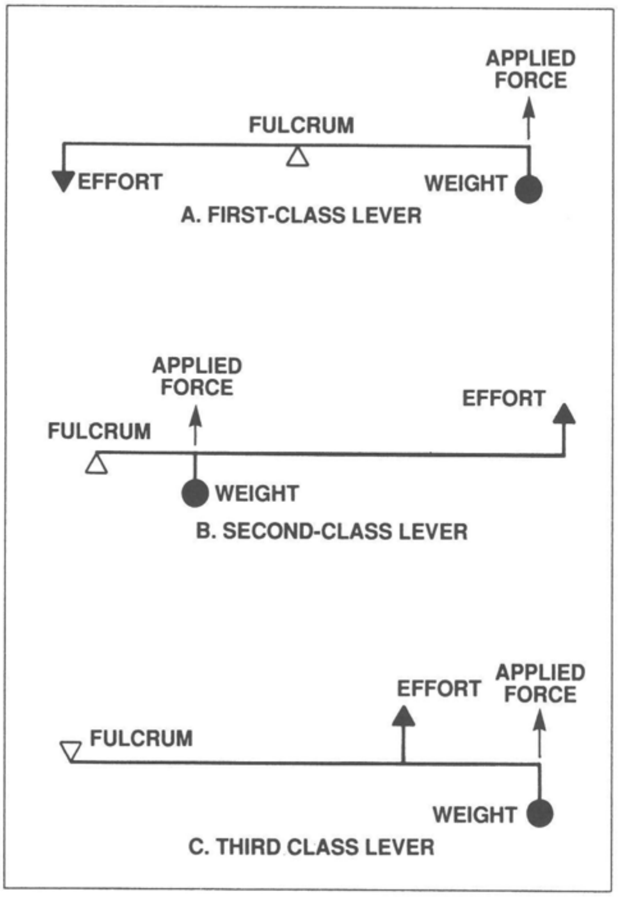


Figure 1-3. Three classes of levers.

help accomplish this are third-class levers. As shown in C of figure 1-3, the fulcrum is at one end of the lever and the weight or resistance to be overcome is at the other end, with the effort applied at some point between. Third-class levers are easily recognized because the effort is applied between the fulcrum and the resistance.

This relationship can be stated in general terms: The length of the effort arm is the same number of times greater than the length of the resistance arm as the resistance to be overcome is greater than the effort that must be applied.

The mathematical equation for this relationship is:

$$\frac{A}{a} = \frac{R}{E}$$

where:

A = Length of effort arm.

a = Length of resistance arm.

R = Resistance weight or force.

E = Effort force.

Remember that all distances must be in the same units, and all forces must also be in the same units.

Mechanical Advantage Of Levers

Levers may provide mechanical advantages, since they can be applied in such manner that they can magnify an applied force. This is true of first- and second-class levers. The third-class lever provides what is called a fractional disadvantage, i.e., one in which a greater force is required than the force of the load lifted.

Mechanical advantage machines are used throughout the aircraft to help the pilot or a motor or hydraulic or pneumatic system to accomplish a task where work is involved.

Work, Energy, And Power

Work

The study of machines, both simple and complex, is in one sense a study of the energy of mechanical work. This is true because all **machines** transfer input energy, or the work done on the machine to output energy, or the work done by the machine.

Work is done when a resistance is overcome by a force acting through a measurable distance. Two factors are involved: (1) **Force** and (2) movement through a **distance**. As an example, suppose a small aircraft is stuck in the snow. Two men push against it for a period of time, but the aircraft does not move. According to the technical definition, no **work** was done in pushing against the aircraft. By definition, work is accomplished only when an object is displaced some distance against a resistive force.

In equation form, this relationship is,

$$\text{Work} = \text{Force } (F) \times \text{distance } (d).$$

The physicist defines **work** as "work is force times displacement. Work done by a force acting on a body is equal to the magnitude of the force multiplied by the distance through which the force acts."

In the metric system, the unit of work is the *joule*, where one joule is the amount of work done by a force of one newton when it acts through a distance of one meter. That is,

$$1 \text{ joule} = 1 \text{ newton-m}$$

Hence we can write the definition in the form

$$W\ (\text{joules}) = F\ (\text{newtons}) \times d\ (\text{meters})$$

If we push a box for 8 m across a floor with a force of 100 newtons, the work we perform is

$$W = Fd = 100 \text{ newtons} \times 8 \text{ m} = 800 \text{ joules}$$

How much work is done in raising a 500-kg (kilogram) elevator cab from the ground floor of a building to its tenth floor, 30 m (meters) higher? We note that the force needed is equal to the weight of the cab.

In the metric system, mass rather than weight is normally specified. To find the weight in **newtons** (the metric unit of force) of something whose mass in kilograms is known, the weight or gravitational force $F = mg$ is used with $g = 9.8 \text{ m/sec}^2$.

$$F\ (\text{newtons}) = m\ (\text{kilograms}) \times g\ (9.8 \text{ m/sec}^2)$$

and

$$W\ (\text{joules}) = m\ (\text{kilograms}) \times g\ (9.8 \text{ m/sec}^2) \times d\ (\text{meters})$$

$$W = Fd = mgd = 500 \text{ kg} \times 9.8 \text{ m/sec}^2 \times 30\text{m}$$
$$W = 147{,}000 \text{ joules}$$
$$W = 1.47 \times 10^5 \text{ joules}$$

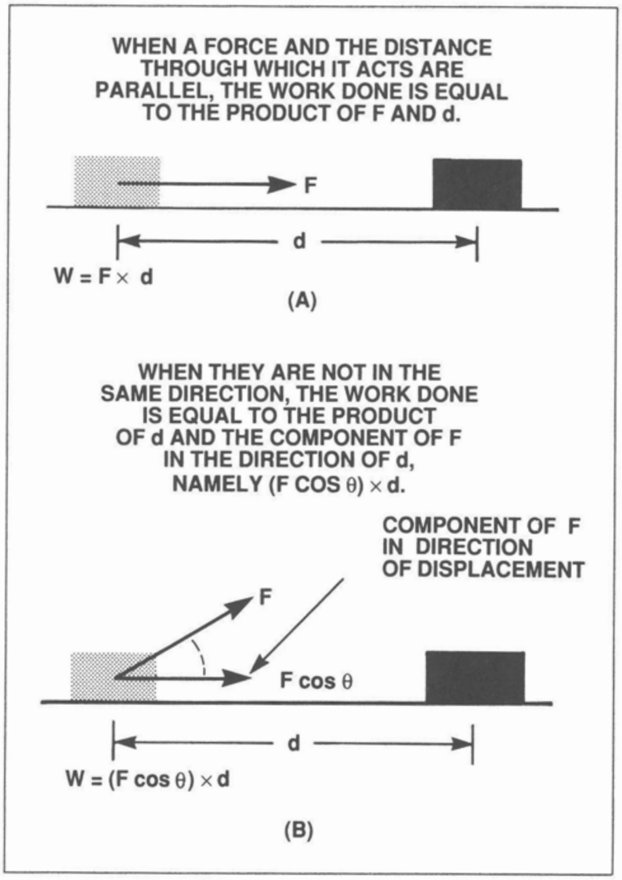


Figure 1-4. Direction of work.

Force Parallel To Displacement

If force is expressed in pounds and distances in feet, work will be expressed in foot-pounds (ft-lbs).

Example:
How much work is accomplished in lifting a 40-pound weight to a vertical height of 25 feet?

$$W = Fd$$
$$W = 40 \text{ lb} \times 25 \text{ ft}$$
$$W = 1{,}000 \text{ ft-lb}$$

Example:
How much work is accomplished in pushing a small aircraft into a hangar a distance of 115 feet if a force of 75 pounds is required to keep it moving?

$$W = Fd$$
$$W = 75 \text{ lb} \times 115 \text{ ft}$$
$$W = 8{,}625 \text{ ft-lb}$$

Force Not Parallel To Displacement

In the equation above, F is assumed to be in the same direction as d. If it is not, for example the case of a body pulling a wagon with a rope not parallel to the ground, we must use F for the component of the applied force that acts in the direction of the motion, figure 1-4(B).

The component of a force in the direction of a displacement d is:

$$F \cos \theta$$

where θ is the angle between F and d. Hence the most general equation for work is

$$\mathbf{W = Fd \cos \theta}$$

When F and d are parallel, $\theta = 0°$ and $\cos \theta = 1$, so that $Fd \cos \theta$ reduces to just Fd. When F and d are perpendicular, $\theta = 90°$ and $\cos \theta = 0$, so that no work is done. A force that is perpendicular to the motion of an object can do no work upon it. Thus gravity, which results in a downward force on everything near the earth, does no work on objects moving horizontally along the earth's surface However, if we drop an object, as it falls to the ground work is definitely done upon it.

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Aircraft Systems for Pilots is a single-source manual of what pilots should know about basic aircraft systems. It includes a study of the fundamentals of physical matter (from which airplanes are made) and mechanics (how airplane parts act and react). Study of each type of system allows the professional pilot to stay abreast of the critical learning that must occur upon advancement into management of more complex aircraft.

Subjects covered include physics, aircraft engine types and construction, reciprocating engine theory, engine lubrication and cooling, propellers and governors, fuels and fuel systems, power management, supercharging and turbocharging, pressurization and high altitude operations, electrical principles, aircraft electrical systems, hydraulic systems and landing gear, pneumatic and deicing systems, weight and balance, instrument systems, inspections, and much more. Study questions conclude each chapter, and the book is illustrated throughout, and indexed.

In print for more than 30 years and continually updated, this Fourth Edition continues to serve as the comprehensive college textbook for pilots learning aircraft systems.

Dr. Dale De Remer received his Bachelor of Science degree from California State Polytechnic University. While completing his Master of Science and Ph.D. at Utah State University, flying became a part of everyday life. He has owned and flown a myriad of different airplanes, seaplanes and helicopters and taken an active part in their maintenance and holds ATP, CFI-A, CFI-H, CFI-I and MEI certificates. He served as corporate pilot, agricultural pilot and chief pilot for various companies while logging over 24,000 hours total time in general aviation aircraft of many kinds. He has more than 22 years experience teaching university level aviation courses and retired with the rank of professor emeritus of aviation from the University of North Dakota. He is recognized as a NAFI Master Flight Instructor and in 1998 he was inducted into the National Association of Flight Instructors Hall of Fame at Oshkosh.

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