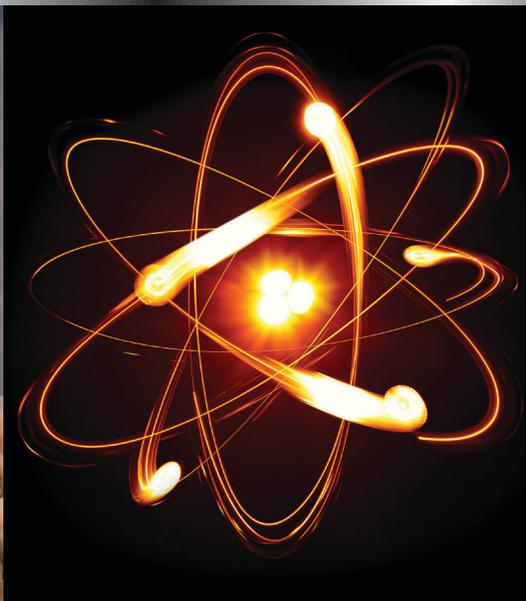# Module 02

FOR B1 & B2 CERTIFICATION

PHYSICS

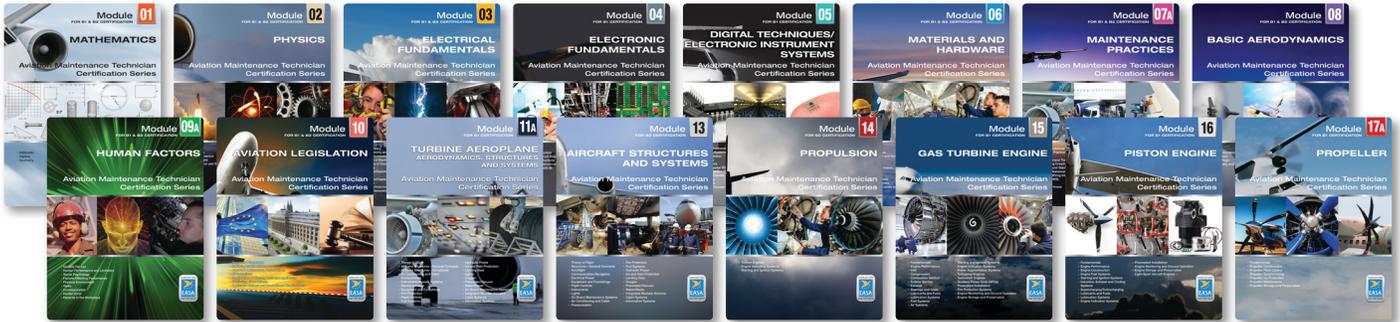## Aviation Maintenance Technician Certification Series

- Matter
- Mechanics
- Thermodynamics
- Optics (Light)
- Wave Motion and Sound

EASA Part-66
Aviation Maintenance Technician
Certification Series

NO COST REVISION/UPDATE SUBSCRIPTION PROGRAM

Complete EASA Part-66 Aviation Maintenance Technician Certification Series

NO COST REVISION/UPDATE PROGRAM

Aircraft Technical Book Company is offering a revision/update program to our customers who purchase an EASA Module from the EASA Aviation Maintenance Technician Certification Series. The update is good for two (2) years from time of registration of any EASA Module or EASA bundled kits. If a revision occurs within two (2) years from date of registration, we will send you the revised pages FREE of cost to the registered email. Go to the link provided at the bottom of this page and fill out the form to be included in the EASA Revision/Update Subscription Program. In an effort to provide quality customer service please let us know if your email you register with changes so we can update our records.

If you have any questions about this process please send an email to: *techsupport@actechbooks.com*

HERE'S HOW IT WORKS

1. All EASA Module Series textbooks contain an EASA subscription page explaining the subscription update process and provide a web site link to register for the EASA Revision/Update Subscription Program.
2. Go to the link provided below and fill out the web based form with your *first and last name, current email address, and school* if applicable.
3. From the time of purchase, if a revision occurs to the Module you have registered for, a revised PDF file containing the pages with edits will be sent to the registered email provided.
4. Please note that we try to keep our records as current as possible. If your email address provided at time of registration changes please let us know as soon as possible so we can update your account.
5. This service is FREE of charge for two (2) years from date of registration.

LINK TO REGISTER FOR REVISION/UPDATE PROGRAM
http://www.actechbooks.com/easasub/m02

PHYSICS

Aviation Maintenance Technician Certification Series

COMPLIANT WITH

EASA
European Aviation Safety Agency

EASA PART 66/147

AIRCRAFT TECHNICAL BOOK COMPANY

AVAILABLE IN
*Printed Edition and Electronic
(eBook) Format*
«
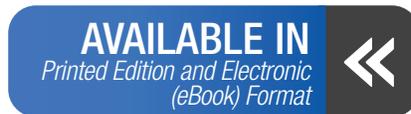
AVIATION MAINTENANCE TECHNICIAN CERTIFICATION SERIES

Contributors	Thomas Forenz
	Nerijus Baublys
Layout/Design	Michael Amrine

Version 3 - Effective Date 07.01.2018

To order books or for Customer Service, please call +1 970 726-5111.

www.actechbooks.com

Printed in the United States of America

9 781941 144701

For comments or suggestions about this book, please call or write to:
1.970.726.5111 | comments@actechbooks.com

AIRCRAFT TECHNICAL BOOK COMPANY

WELCOME

The publishers of this Aviation Maintenance Technician Certification Series welcome you to the world of aviation maintenance. As you move towards EASA certification, you are required to gain suitable knowledge and experience in your chosen area. Qualification on basic subjects for each aircraft maintenance license category or subcategory is accomplished in accordance with the following matrix. Where applicable, subjects are indicated by an "X" in the column below the license heading.

For other educational tools created to prepare candidates for licensure, contact Aircraft Technical Book Company.

We wish you good luck and success in your studies and in your aviation career!

REVISION LOG

VERSION	EFFECTIVE DATE	DESCRIPTION OF CHANGE
001	2013 12	Module Creation and Release
002	2016 11	Format Update - Appearance Update
003	2018 07	Sections adjusted for improved alignment with Part 66 Appendix 1
		Content added for increased depth in the following areas:
		Sub-Module 01 - Elasticity; Sub-Module 02 – Harmonics, Velocity Ratio, Inertia, Total Energy,
		Coefficient of Friction, Compressibility; Sub-Module 04 – Reflection;
		Sub-Module 05 – Wave Motion, Production of Sound

FORWARD

PART-66 and the Acceptable Means of Compliance (AMC) and Guidance Material (GM) of the European Aviation Safety Agency (EASA), Appendix 1 establishes the Basic Knowledge Requirements for those seeking an aircraft maintenance license. The information in this Module of the Aviation Maintenance Technical Certification Series published by the Aircraft Technical Book Company meets or exceeds the breadth and depth of knowledge subject matter referenced in Appendix 1 of the Implementing Rules. However, the order of the material presented is at the discretion of the editor in an effort to convey the required knowledge in the most sequential and comprehensible manner. Knowledge levels required for Category A1, B1, B2, and B3 aircraft maintenance licenses remain unchanged from those listed in Appendix 1 Basic Knowledge Requirements. Tables from Appendix 1 Basic Knowledge Requirements are reproduced at the beginning of each module in the series and again at the beginning of each Sub-Module.

How numbers are written in this book:

This book uses the International Civil Aviation Organization (ICAO) standard of writing numbers. This method displays large numbers by adding a space between each group of 3 digits. This is opposed to the American method which uses commas and the European method which uses periods. For example, the number one million is expressed as so:

ICAO Standard	1 000 000
European Standard	1.000.000
American Standard	1,000,000

SI Units:

The International System of Units (SI) developed and maintained by the General Conference of Weights and Measures (CGPM) shall be used as the standard system of units of measurement for all aspects of international civil aviation air and ground operations.

Prefixes:

The prefixes and symbols listed in the table below shall be used to form names and symbols of the decimal multiples and submultiples of International System of Units (SI) units.

MULTIPLICATION FACTOR		PREFIX	SYMBOL
1 000 000 000 000 000 000	$= 10^{18}$	exa	E
1 000 000 000 000 000	$= 10^{15}$	peta	P
1 000 000 000 000	$= 10^{12}$	tera	T
1 000 000 000	$= 10^{9}$	giga	G
1 000 000	$= 10^{6}$	mega	M
1 000	$= 10^{3}$	kilo	k
100	$= 10^{2}$	hecto	h
10	$= 10^{1}$	deca	da
0.1	$=10^{-1}$	deci	d
0.01	$= 10^{-2}$	centi	c
0.001	$= 10^{-3}$	milli	m
0.000 001	$= 10^{-6}$	micro	µ
0.000 000 001	$= 10^{-9}$	nano	n
0.000 000 000 001	$= 10^{-12}$	pico	p
0.000 000 000 000 001	$= 10^{-15}$	femto	f
0.000 000 000 000 000 001	$= 10^{-18}$	atto	a

International System of Units (SI) Prefixes

EASA LICENSE CATEGORY CHART

Module Number and Title		A1 Airplane Turbine	B1.1 Airplane Turbine	B1.2 Airplane Piston	B1.3 Helicopter Turbine	B2 Avionics
1	Mathematics	X	X	X	X	X
2	Physics	X	X	X	X	X
3	Electrical Fundamentals	X	X	X	X	X
4	Electronic Fundamentals		X	X	X	X
5	Digital Techniques / Electronic Instrument Systems	X	X	X	X	X
6	Materials and Hardware	X	X	X	X	X
7A	Maintenance Practices	X	X	X	X	X
8	Basic Aerodynamics	X	X	X	X	X
9A	Human Factors	X	X	X	X	X
10	Aviation Legislation	X	X	X	X	X
11A	Turbine Aeroplane Aerodynamics, Structures and Systems	X	X			
11B	Piston Aeroplane Aerodynamics, Structures and Systems			X		
12	Helicopter Aerodynamics, Structures and Systems				X	
13	Aircraft Aerodynamics, Structures and Systems					X
14	Propulsion					X
15	Gas Turbine Engine	X	X		X	
16	Piston Engine			X		
17A	Propeller	X	X	X		

GENERAL KNOWLEDGE REQUIREMENTS
MODULE 02 SYLLABUS AS OUTLINED IN PART-66, APPENDIX 1

Level 1

A familiarization with the principal elements of the subject.

Objectives:
a. The applicant should be familiar with the basic elements of the subject.
b. The applicant should be able to give a simple description of the whole subject, using common words and examples.
c. The applicant should be able to use typical terms.

Level 2

A general knowledge of the theoretical and practical aspects of the subject and an ability to apply that knowledge.

Objectives:
a. The applicant should be able to understand the theoretical fundamentals of the subject.
b. The applicant should be able to give a general description of the subject using, as appropriate, typical examples.
c. The applicant should be able to use mathematical formula in conjunction with physical laws describing the subject.
d. The applicant should be able to read and understand sketches, drawings and schematics describing the subject.
e. The applicant should be able to apply his knowledge in a practical manner using detailed procedures.

Level 3

A detailed knowledge of the theoretical and practical aspects of the subject and a capacity to combine and apply the separate elements of knowledge in a logical and comprehensive manner.

Objectives:
a. The applicant should know the theory of the subject and interrelationships with other subjects.
b. The applicant should be able to give a detailed description of the subject using theoretical fundamentals and specific examples.
c. The applicant should understand and be able to use mathematical formula related to the subject.
d. The applicant should be able to read, understand and prepare sketches, simple drawings and schematics describing the subject.
e. The applicant should be able to apply his knowledge in a practical manner using manufacturer's instructions.
f. The applicant should be able to interpret results from various sources and measurements and apply corrective action where appropriate.

Sub–Module 01 – Matter

	B1	B2
Nature of matter: the chemical elements, structure of atoms, molecules; Chemical compounds. States: solid, liquid and gaseous; Changes between states.	1	1

Sub–Module 02 – Mechanics
2.2.1 – Statics

	B1	B2
Forces, moments and couples, representation as vectors; Center of gravity; Elements of theory of stress, strain and elasticity: tension, compression, shear and torsion; Pressure and buoyancy in liquids (barometers).	2	1

2.2.2 – Kinetics

	B1	B2
Linear movement: uniform motion in a straight line, motion under constant acceleration (motion under gravity); Rotational movement: uniform circular motion (centrifugal/centripetal forces); Periodic motion: pendular movement; Simple theory of vibration, harmonics and resonance; Velocity ratio, mechanical advantage and efficiency.	2	1

2.2.3 – Dynamics

	B1	B2
(a) Mass: Force, inertia, work, power, energy (potential, kinetic and total energy), heat, efficiency;	2	1
(b) Momentum, conservation of momentum; Impulse; Gyroscopic principles; Friction: nature and effects, coefficient of friction (rolling resistance).	2	2

2.2.4 – Fluid Dynamics

	B1	B2
(a) Specific gravity and density;	2	2
(b) Viscosity, fluid resistance, effects of streamlining; Effects of compressibility on fluids Static, dynamic and total pressure: Bernoulli's Theorem, venturi.	2	1

Sub-Module 03 – Thermodynamics

(a) Temperature: thermometers and temperature scales: Celsius, Fahrenheit and Kelvin;
Heat definition;

B1	B2
2	2

(b) Heat capacity, specific heat;
Heat transfer: convection, radiation and conduction;
Volumetric expansion;
First and second law of thermodynamics;
Gases: ideal gases laws; specific heat at constant volume and constant pressure, work done by expanding gas;
Isothermal, adiabatic expansion and compression, engine cycles, constant volume and constant pressure, refrigerators and heat pumps;
Latent heats of fusion and evaporation, thermal energy, heat of combustion.

B1	B2
2	2

Sub-Module 04 – Optics (Light)

Nature of light; speed of light;
Laws of reflection and refraction: reflection at plane surfaces, reflection by spherical mirrors, refraction, lenses;
Fiber optics.

B1	B2
2	2

Sub-Module 05 – Wave Motion and Sound

Wave motion: mechanical waves, sinusoidal wave motion, interference phenomena, standing waves;
Sound: speed of sound, production of sound, intensity, pitch and quality, Doppler effect.

B1	B2
2	2

PHYSICS

SUB-MODULE 01
MATTER

SUB-MODULE 02
MECHANICS

CONTENTS

PHYSICS

MATTER

SUB-MODULE 01

PART-66 SYLLABUS	LEVELS	
CERTIFICATION CATEGORY →	**B1**	**B2**

Sub-Module 01
MATTER
Knowledge Requirements

2.1 – Matter

	B1	B2
Nature of matter: the chemical elements, structure of atoms, molecules; Chemical compounds. States: solid, liquid and gaseous; Changes between states.	1	1

AIRCRAFT
TECHNICAL
BOOK COMPANY

2.1 - MATTER

Matter is the foundation for any discussion of physics. Matter is what all things are made of; whatever occupies space, has mass, and is perceptible to the senses in some way. According to the Law of Conservation, matter cannot be created or destroyed, but it is possible to change its physical state. When liquid gasoline vaporizes and mixes with air, and then burns, it might seem that this piece of matter has disappeared and no longer exists. Although it no longer exists in the state of liquid gasoline, the matter still exists in the form of the gases given off by the burning fuel.

NATURE OF MATTER

All matter is made up of atoms. An atom is the smallest unit of matter that establishes the unique characteristics of a substance. There are over 100 different kinds of matter each made up of atoms with different physical attributes. These varied and unique kinds of matter are called elements. They cannot be further broken down into simpler substances without losing their unique identity.

Atoms of different elements are similar to each other in that they contain the same basic parts. An atom has a nucleus within the nucleus are subatomic particles. One or more protons are found at the nucleus of all atoms. The proton has a positive electrical charge. One or more neutrons are also found at the nucleus of all atoms. A neutron has no electrical charge. Orbiting around the nucleus is a third kind of subatomic particle called an electron. An electron has a negative electrical charge. Electrons are configured around the nucleus in orderly, concentric rings known as shells. *Figure 1-1* illustrates the basic structure and components of atoms.

Generally, each atom contains the same number of electrons and neutrons as the atom has protons. However, the number of these particles that each atom contains is what causes the elements to be different. For example, an atom of hydrogen, has one proton, one neutron and one electron. It is the simplest element. An atom of Oxygen, has eight protons, eight neutrons and eight electrons. Copper has 29 of each of these subatomic particles and so forth. The number of subatomic particles that each atom contains defines the type of element it is and its inherent properties. The mass of an atom is related to how many characteristic subatomic particles make up the atom of each element.
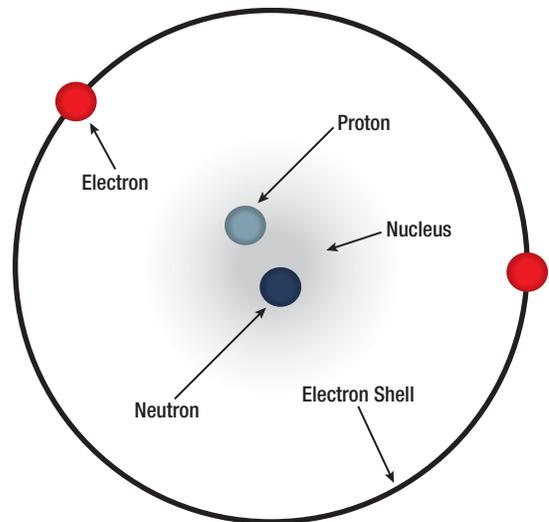
Figure 1-1. An atom and its sub-atomic particles.

Elements are assigned an atomic number according to how many protons are found at the nucleus of their atoms. Each element also has a distinctive 1, 2, or 3 letter abbreviation. The elements are arrange in a table known as the periodic table of elements. The table groups the elements by periods horizontally and by groups vertically to show similar characteristics of the elements. (*Figure 1-2*)

Atoms of the same or different elements may chemically bond to form a molecule. When two or more atoms of the same element bond to form a molecule, it will have the inherent properties of that element. When atoms of different elements bond to form a molecule, the molecule has properties and characteristics completely different than those of each individual elements that comprise it. A water molecule, for example, is made up of two hydrogen atoms and one oxygen atom. Water has its own unique properties that are completely different than those of hydrogen or oxygen alone.

When atoms bond to form molecules, they share electrons. The closest shell to the nucleus can only contain two orbiting electrons. If the atom has more than two electrons, they are found in the next orbital shell farther away from the nucleus. This second shell can only hold eight electrons. If the atom has more than ten electrons (2 first shell + 8 second shell), they orbit in a third shell farther out from the nucleus. This third shell is filled with up to eight electrons and then

PERIODIC TABLE
of the
ELEMENTS

ELEMENT STATE at 0°C and 1 atm

*	Solid
**	Liquid
***	Gas

Element Name
Atomic Number
Symbol
Atomic Weight
( ) estimates
Element State

Gold
Au 79
Atomic Weight = 196.97
*

ELEMENT CATEGORIES

- ALKALI METALS
- ALKALI EARTH METALS
- LANTHANIDES
- ACTINIDES
- TRANSITION ELEMENTS
- OTHER METALS
- METALLOIDS
- OTHER NONMETALS
- HALOGENS
- NOBEL GASES
- UNKNOWN CHEMICAL PROPERTIES

Figure 1-2. The periodic table of elements.

AIRCRAFT TECHNICAL BOOK COMPANY

a fourth shell starts to fill if the element still has more electrons. However, when the fourth shell contains eight electrons, the number of electrons in the third shell begins to increase again until a maximum of 18 is reached. (*Figure 1-3*)

The outer most orbital shell of any atom's electrons is called the valence shell. The number of electrons in the valence shell determines the chemical bonding properties of the material as well as other characteristics such as conductivity. When the valence shell has the maximum number of electrons, it is complete and the electrons tend to be bound strongly to the nucleus. Materials with this characteristic are chemically stable. It takes a large amount of force to move the electrons in this situation from one atom valence shell to that of another. Since the movement of electrons is called electric current, substances with complete valence shells are known as good insulators because they resist the flow of electrons (electricity). (*Figure 1-4*)

In atoms with an incomplete valence shell, that is, those without the maximum number of electrons in their valence shell, the electrons are bound less strongly to the nucleus. The material is chemically disposed to combine with other materials or other identical atoms to fill in the unstable valence configuration and bring the number of electrons in the valence shell to maximum. Two or more substances may share the electrons in their valence shells and form a covalent bond. A covalent bond is the method by which atoms complete their valence shells by sharing valence electrons with other atoms. Molecules are formed this way.

Electrons in incomplete valence shells may also move freely from valence shell to valence shell of different atoms or compounds. In this case, these are known as free electrons. As stated, the movement of electrons is known as electric current or current flow. When electrons move freely from atom to atom or compound to compound, the substance is known as a conductor. (*Figure 1-5*)

ISOTOPES

When atoms of the same element have different numbers of neutrons, they are called isotopes. Because of the differing numbers of neutrons, various isotopes of the same element have different masses. Mass is the word for how much matter something has and therefore how much it weighs. Because different isotopes have different numbers of neutrons, they do not all weigh the same. Different isotopes of the same element have the same atomic number because they have the same number of protons. The atomic number is decided by the number of protons. (*Figure 1-6*)

Shell or Orbit Number	1	2	3	4	5
Maximum Number Of Electrons	2	8	18	32	50

Figure 1-3. Maximum number of electrons in each orbital shell of an atom.

Aluminum   Copper   Silver   Gold
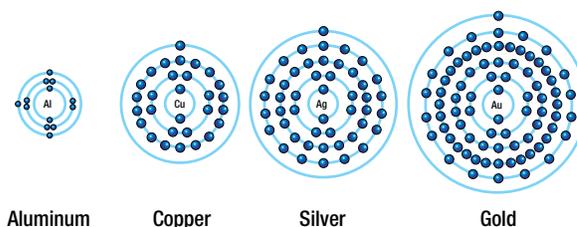
Figure 1-5. The valence shells of elements that are common conductors have one (or three) electrons.

Felium   Neon   Argon   Krypton

Figure 1-4. Elements with full valence shells are good insulators. Most insulators used in aviation are compounds of two or more elements that share electrons to fill their valence shells.

Hydrogen-1
mass number: 1

Hydrogen-2, deuterium
mass number: 2

Hydrogen-3, tritium
mass number: 3
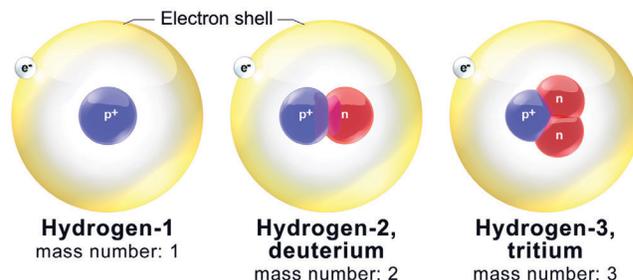
Figure 1-6. Isotopes of hydrogen.

Isotopes of the same element also have the same number of electrons and the same electronic structure. Because how an atom acts is decided by its electronic structure, isotopes are almost the same chemically, but they are different physically because of their different masses.

Hydrogen, the most common element, has three common isotopes. Its most common isotope with only one proton and no neutrons is called protium (^{1}H). A hydrogen atom with one proton and one neutron (atomic mass of 2) is called deuterium(^{2}H). A hydrogen atom with one proton and two neutrons (atomic mass of 3) is called tritium(^{3}H). Protium and deuterium are stable isotopes, while tritium is a radioactive isotope.

CHEMICAL COMPOUNDS

Materials made up of two or more elements that have chemically bonded are known as compounds. Compounds have properties different than the elements from which they are made. They can only be separated through chemical reaction. They have a unique chemical structure with a fixed ratio of atoms of different elements that are bonded together chemically. Compounds should not be confused with mixtures. Mixtures are atoms and molecules that are physically mixed together but are not chemically bonded. The properties and characteristics of a mixture are closely related or dependent on the properties of the individual constituents. Mixtures can usually be separated by filtering, evaporation or some other mechanical means.

STATES OF MATTER

Matter exists in four common states; solids, liquids, gases and plasma. A state of matter is the physical condition of a substance. Solids, liquids and gases are the primary states of matter of concern for the aviation maintenance professional. The compound(s) from which a substance is made do not change, regardless of the state of matter. Atoms and molecules that make up a substance are always in a state of motion due to heat energy in the material. The physical state of matter is related to the degree of motion between these particles with solids having the least motion and gases and plasma having the most.

PLASMA

Plasma is a unique state of matter comprised of ionized gas consisting of positive ions and free electrons in proportions resulting in a relatively neutral electric charge. Its particles are close enough together that they act collectively when exposed to a magnetic field. Plasma is also electrically conductive. It is sustained easily at the extremely high temperatures present in stars and as such is the most common form of matter in the universe.

SOLID

Matter is said to be solid when it has a definite volume and shape. The molecules of a solid are tightly bound to each other. They resist changing shape or volume. Solids may be geometrically or irregularly structured. They are incompressible and do not contain enough movement of the molecules to permit a physical change of shape.

LIQUID

Liquid matter is characterized by molecules that have more energy and increased movement. This causes the molecules to be able flow and not take a rigid shape such as a solid. Liquids take the shape of their container even though the volume of a liquid does not change significantly. Liquids are said to be incompressible. While liquid molecules are able to slide past each other, they are still closely packed enough that the application of pressure does little to change the volume. The molecules are also closely bound enough to each other that surface tension is created. Surface tension keeps liquids from complete freedom of expansion. It can be observed when a container is filled with a liquid to slightly over the brim yet the liquid does not spill over.

GAS

Matter also exists as a gas. This type of matter contains even more heat energy and movement in its molecules. The bonding that causes surface tension in a liquid does not exist in a gas. A greater space between molecules exists. Gases take the shape of their container but unlike liquids, gases are compressible. When pressure is applied, the molecules can be made to exist closer to each other. It is possible to put a gas under so much pressure that it changes to a liquid state.

CHANGES BETWEEN STATES

Matter can change between the states by adding or removing energy. The chemical composition of the material remains the same during all states of matter but the energy level causes it to be a solid, liquid, or gas. For example, water is always H_2O, millions of pairs of hydrogen atoms covalently bonded to a single oxygen atom loosely held next to each other in a liquid state.

When energy is removed and water becomes ice, it is still H_2O. However, the motion of the molecules is greatly reduced and they no longer have the energy to slide past one another as a liquid. The same is true when heat energy is added to water. Water vapor is formed as the motion of the molecules causes more freedom of movement between molecules. But the water existing as a gas (vapor) is still formed from millions of H_2O molecules.

The heat energy added or subtracted to a substance is typically measured by temperature. The higher the temperature of a substance, the more energy it contains. Heat always flows from hot to cold. These terms (hot and cold) express the relative amount of energy present in the substance. They do not measure the absolute amount of heat present. Without a difference in energy levels, there is no transfer of energy (heat).

Adding heat to a substance does not always raise its temperature. When a substance changes state, such as when a liquid changes into a vapor, heat energy is absorbed. This is called latent heat. When a vapor condenses into a liquid, this heat energy is given off. The temperature of a substance remains constant during its change of state. All energy absorbed or given off, the latent heat, is used for the change process. Once the change of state is complete, heat added to a substance raises the temperature of the substance. After a substance changes state into a vapor, the rise in temperature of the vapor caused by the addition of still more heat is called superheat.

The temperature at which a substance changes from a liquid into a vapor when heat is added is known as its boiling point. This is the same temperature at which a vapor condenses into a liquid when heat is removed. The boiling point of any substance varies directly with pressure. When pressure on a liquid is increased, its boiling point increases, and when pressure on a liquid is decreased, its boiling point also decreases. For example, water boils at 100 °C (212 °F) at normal atmospheric pressure (14.7 psi). When pressure on liquid water is increased to 20 psi, it does not boil at 100 °C. More energy is required to overcome the increase in pressure. It boils at approximately 108 °C (226.4 °F). The converse is also true. Water can also boil at a much lower temperature simply by reducing the pressure upon it. With only 10 psi of pressure upon liquid water, it boils at 90 °C (194 °F). (*Figure 1-7*)
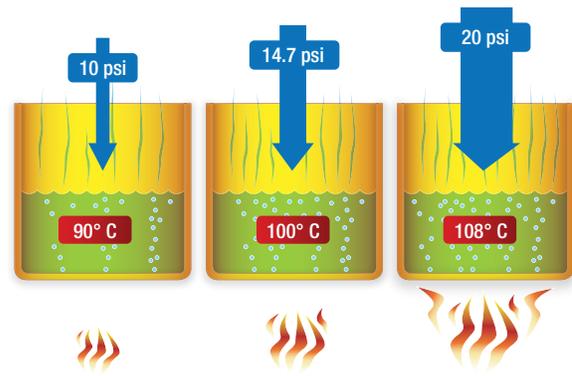
Figure 1-7. Boiling point of water changes as pressure changes.

Vapor pressure is the pressure of the vapor that exists above a liquid that is in an enclosed container at any given temperature. The vapor pressure developed by various substances is unique to each substance. A substance that is said to be volatile, develops high vapor pressure at standard day temperature 15 °C (59 °F). This is because the boiling point of the substance is much lower. The vapor pressure of any substance varies directly with temperature.

CATALYST

A catalyst is a substance that causes or accelerates a chemical reaction without itself being affected. A two part epoxy mix is a good example of a catalyst. The main ingredient is the epoxy resin itself. The second ingredient, when mixed with the resin, causes the resin to harden faster and then remains as part of the epoxy resin mix. The opposite of a catalyst is an inhibitor. Inhibitors slow down reactions.

AIRCRAFT
TECHNICAL
BOOK COMPANY

Question: 1-1
What is matter and in what four states is it found?

Question: 1-2
Name two characteristics affected by the number of electrons in the valence shell of an atom.

Question: 1-3
What is the different between a compound and a mixture?

Question: 1-4
What is the Law of Conservation?

Question: 1-5
What is the principle difference between one element and another?

Question: 1-6
What is the main factor which determines whether one element is able to combine with another to form molecules?

Question: 1-7
What determines how much a material weighs?

Question: 1-8
What is the principle factor which determines what state of matter an element is in?

ANSWERS

Answer: 1-1
Matter is what all things are made of - whatever occupies space, has mass, and is perceptible to the senses in some way. The four states of matter are solids, liquids, gases and plasmas.

Answer: 1-2
Its ability to combine with other atoms; whether the material is a conductor or insulator.

Answer: 1-3
Chemical bonding properties and conductivity.

Answer: 1-4
Matter can not be created or destroyed. It can only be changed from one physical state to another.

Answer: 1-5
The number of protons, neutrons, and electrons within its atom.

Answer: 1-6
The number of electrons each the atom's outer shell.

Answer: 1-7
The number of protons and neutrons in the nucleus of its atom.

Answer: 1-8
Its temperature.

SUB-MODULE 02

Sub-Module 02
MECHANICS
Knowledge Requirements

	CERTIFICATION CATEGORY →	B1	B2
2.2 – Mechanics			
2.2.1 – Statics			
	Forces, moments and couples, representation as vectors;	2	1
	Center of gravity;		
	Elements of theory of stress, strain and elasticity: tension, compression, shear and torsion;		
	Pressure and buoyancy in liquids (barometers).		
2.2.2 – Kinetics			
	Linear movement: uniform motion in a straight line, motion under constant acceleration (motion under gravity);	2	1
	Rotational movement: uniform circular motion (centrifugal/centripetal forces);		
	Periodic motion: pendular movement;		
	Simple theory of vibration, harmonics and resonance;		
	Velocity ratio, mechanical advantage and efficiency.		
2.2.3 – Dynamics			
(a)	Mass: Force, inertia, work, power, energy (potential, kinetic and total energy), heat, efficiency;	2	1
(b)	Momentum, conservation of momentum;	2	2
	Impulse;		
	Gyroscopic principles;		
	Friction: nature and effects, coefficient of friction (rolling resistance).		
2.2.4 – Fluid Dynamics			
(a)	Specific gravity and density;	2	2
(b)	Viscosity, fluid resistance, effects of streamlining;	2	1
	Effects of compressibility on fluids;		
	Static, dynamic and total pressure: Bernoulli's Theorem, venturi.		

2.2.1 - STATICS

FORCES, MOMENTS AND COUPLES

Force is the influence tending to change the motion of a body or produce stress in a stationary body. The magnitude of such an influence on a moving body is often calculated by multiplying the mass of the body by its acceleration. The effect of force acting on a stationary body or structure is stress. There are different types of stress which are discussed below. The forces acting on a stationary body are typically measured in pounds or newtons. When force is applied some distance from the point at which the effects of the force are being considered, the force measurement includes a distance component such as pound-inches.

A force not only has a certain magnitude but it also has a specific direction. Because of this, forces are frequently represented by vectors. This is evident in discussions on aerodynamics (*Module 08*) and weight and balance (*Module 07A*). In both of these disciplines, it is possible to consider forces that impinge on the aircraft around a central point. In aerodynamics, the point is the center of lift. In weight and balance computations, the point is the center of gravity.

A vector is represented by an arrow that points in the direction the force is applied. The longer the arrow, the greater the force. Using geometry, vectors representing forces in different directions can be consolidated into a single vector pointing in a direction that is the resultant of the directional forces applied. An example of this is given later in section 2.2.2 Kinetics/Speed and Velocity.

If two equal forces act on the same point of a rigid body but in exact opposite directions, they cancel each other out. It is as if there are no applied forces. When two forces are equal in magnitude and in opposite directions but are applied to the body parallel to each other, the forces are said to be coupled. As long as the coupled forces are not applied at the same point, they produce a rotating force upon the body to which they are applied. The resultant movement caused by the coupled forces is known as torque. A moment is the distance between an applied force and a reference point. But a moment torque of coupled forces is independent of any particular reference point making it a free vector.

CENTER OF GRAVITY

The center of gravity (CG) of an aircraft is the balance point for the aircraft. An aircraft suspended from this point has no tendency to rotate in either a nose-up or nose-down attitude. The CG is the point about which the weight of an airplane (or any object) is concentrated.

An arm is the horizontal distance that a part of the aircraft or a piece of equipment is located from a manufacturer specified reference point called the datum. A moment is the product of a weight (force) multiplied by its arm. The moment for a piece of equipment installed on an aircraft is in fact a torque value, measured in inch-pounds (in-lb) or newton-meters. Calculations are performed using the weight of various components and their respective distances to the aircraft datum in order to ensure that the center of gravity of an aircraft remains unchanged or within an acceptable range.

Maintenance personnel are required to incorporate center of gravity considerations during routine inspections as well as when the aircraft is modified with new equipment. Flight personnel must also insure the CG remains within safe limits when loading passengers, baggage and fuel. The procedure for proper weight and balance calculations as they relate to the center of gravity are discussed in *Module 07A* of this series.

ELEMENTS OF STRESS, STRAIN, AND STRESS

ELEMENTS OF THEORY OF STRESS

Whenever an aircraft is in operation, it experiences something called stress. External forces are applied to the airframe and engine components. Reactionary force inside the materials of the components counter the external forces. This internal resistance to deformation is known as stress. There are five major stresses to which all aircraft are subjected: (*Figure 2-1*)
- Tension
- Shear
- Compression
- Bending
- Torsion

Tension
Tension is the stress that resists a force that tends to pull something apart. (*Figure 2-1A*) The engine pulls the aircraft forward, but air resistance tries to hold it back.
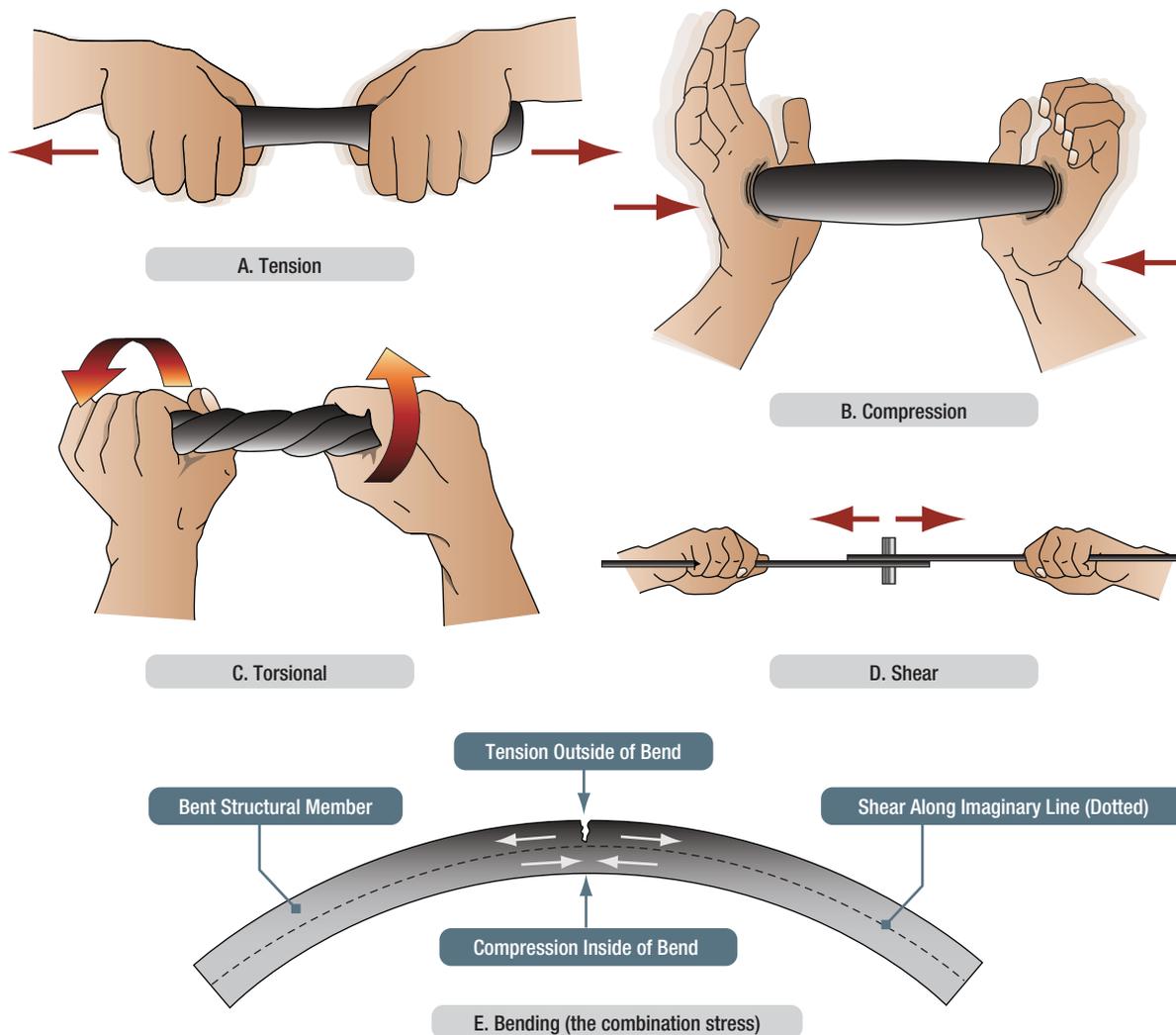
Figure 2-1. The five stresses that may act on an aircraft and its parts.

The result is tension, which stretches the aircraft. The tensile strength of a material is measured in pounds per square inch (psi) and is calculated by dividing the load (in units of weight) required to pull the material apart by its cross-sectional area (in distance squared).

Compression

Compression is the stress that resists a crushing force. (***Figure 2-1B***) The compressive strength of a material is also measured in psi. Compression is the stress that tends to shorten or squeeze aircraft parts.

Torsion

Torsion is the stress that resists twisting. (***Figure 2-1C***) While moving the aircraft forward, the engine also tends to twist it to one side, but other aircraft components hold it on course. Thus, torsion is created. The torsion strength of a material is its resistance to twisting or torque.

Shear

Shear is the stress that resists the force tending to cause one layer of a material to slide over an adjacent layer. (***Figure 2-1D***) Two riveted plates in tension subject the rivets to a shearing force. Usually, the shearing strength of a material is either equal to or less than its tensile or compressive strength. Aircraft parts, especially screws, bolts, and rivets, are often subject to a shearing force.

Bending Stress

Bending stress is a combination of compression and tension. The rod in ***Figure 2-1E*** has been shortened (compressed) on the inside of the bend and stretched on the outside of the bend.

An airplane in flight experiences a bending force on the wing as aerodynamic lift tries to raise the wing. This force of lift actually causes the skin on the top of the wing to compress and the skin on the bottom of the wing

to be under tension. When the airplane is on the ground sitting on its landing gear, the force of gravity tries to bend the wing downward, subjecting the bottom of the wing to compression and the top of the wing to tension. (*Figure 2-2*) During certification testing, an aircraft manufacturer intentionally bends the wing up and down to make sure it can take the stress without failing.

Strength or resistance to the external loads imposed during operation are the principle design requirement in certain structures. However, there are numerous other characteristics in addition to and controlling the five major stresses that engineers must consider. For example, cowling, fairings, and similar parts may not be subject to significant loads requiring a high degree of strength. However, these parts must have streamlined shapes to meet aerodynamic requirements, such as reducing drag or directing airflow.

STRAIN

If the stress acting on an object is great enough, it can cause the object to change its shape or to become distorted. One characteristic of matter is that it tends to be elastic, meaning it can be forced out of shape when a force is applied, and then return to its original shape when the force is removed. When an object becomes distorted by an applied force, the object is said to be strained.

On turbine engine test cells, the thrust of the engine is typically measured by what are called strain gages. When the force (thrust) of the engine is pulling out against the strain gages, the amount of distortion is measured and then translated into the appropriate thrust reading.

A deflecting beam style of torque wrench uses the strain on the drive end of the wrench and the resulting distortion of the beam to indicate the amount of torque on a bolt or nut. (*Figure 2-3*)

Figure 2-3. Deflecting beam torque wrench, measures strain by distortion.

ELASTICITY

Elasticity is the ability of a material to return to its original shape after being effected by a force such as stretching or bending. Examples of elastic materials include a rubber band or a metal spring. The reasons for elasticity can be different for different materials. In metals, the atomic structure changes when force is applied. When forces are removed, the structure goes back to the original state. For rubber and some other materials, elasticity is caused by the stretching of the atomic structure when forces are applied.

A flexible aircraft wing is a good example of elasticity in aviation. If it were not for the ability of a wing to flex and return to its normal shape when stressed, it would be much more likely to fail during turbulence, hard landings, or when under other stresses. The opposite of elasticity is rigidity. (*Figure 2-4*)

PRESSURE AND BUOYANCY IN LIQUIDS

FLUID PRESSURE

The pressure exerted on the bottom of a container by a liquid is determined by the height of the liquid and not by the shape of the container. This can be seen in *Figure 2-5*, where three different shapes and sizes of containers

Figure 2-2. Airplane on the ground, wing under tension and compression.

Figure 2-4. Elasticity of a modern aircraft wing aids when absorbing of stress for structural integrity and for passenger comfort.

are full of colored water. Even though they are different shapes and have different volumes of liquid, each one has a height of 231 inches. Because of this height, each one would exert a pressure on the bottom of 8.34 psi. The container on the left, with a surface area of 1 in², contains a volume of 231 in³ (one gallon). One gallon of water weighs 8.34 lb, which is why the pressure on the bottom is 8.34 psi.

Still thinking about *Figure 2-5*, if the pressure was measured half way down, it would be half of 8.34, or 4.17 psi. In other words, the pressure is adjustable by varying the height of the column. Pressure based on the column height of a fluid is known as static pressure. With liquids, such as gasoline, it is sometimes referred to as a head of pressure. For example, if a carburetor needs to have 2 psi supplied to its inlet (head of pressure), this could be accomplished by having the fuel tank positioned the appropriate number of inches higher than the carburetor.

As identified in the previous paragraph, pressure due to the height of a fluid column is known as static pressure. When a fluid is in motion, and its velocity is converted to pressure, that pressure is known as ram. When ram pressure and static pressure are added together, the result is known as total pressure. In the inlet of a gas turbine engine, for example, total pressure is often measured to provide a signal to the fuel metering device or to provide a signal to a gauge on the flight deck.

This same principle of pressure caused by a column of fluid applies to the earth's atmosphere. Air is a fluid that has weight. This weight causes atmospheric pressure. On

Each container is filled with colored water to a height of 231 inches.
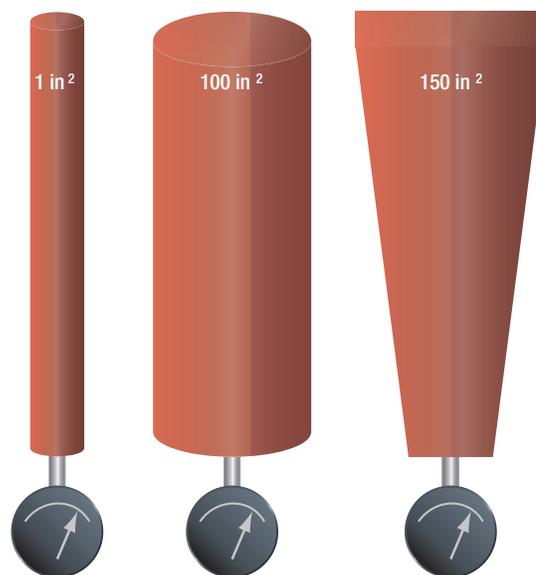
Each Pressure Gauge reads 8.34 psi

Figure 2-5. Fluid pressure based on column height.

a standard day at sea level, if a 1 square inch column of air extending to the top of the atmosphere is weighed, it would weigh 14.7 lb. That is why standard day atmospheric pressure is said to be 14.7 pounds per square inch (14.7 psi).

Since atmospheric pressure at any altitude is due to the weight of air above it, pressure decreases with increased altitude. Obviously, the total weight of air above an area at 15 000 ft would be less than the total weight of the air above an area at 10 000 ft.

Atmospheric pressure is often measured by a mercury barometer. A glass tube somewhat over 30 inches in length is sealed at one end and then filled with mercury. It is then inverted and the open end placed in a dish of mercury. Immediately, the mercury level in the inverted tube will drop a short distance, leaving a small volume of mercury vapor at nearly zero absolute pressure in the tube just above the top of the liquid mercury column. Gravity acting on the mercury in the tube will try to make the mercury run out. Atmospheric pressure pushing down on the mercury in the open container tries to make the mercury stay in the tube. At some point these two forces (gravity and atmospheric pressure) will equalize and the mercury will stabilize at a certain height in the tube. Under standard day atmospheric conditions, the air in a 1 square inch column extending to the top of the atmosphere weighs 14.7 lb. A 1 square inch column of mercury, 29.92 inches tall, also weighs 14.7 lb. That is why 14.7 psi is equal to 29.92 "Hg when referring to a barometric reading. *Figure 2-6* demonstrates this point.

A second means of measuring atmospheric pressure is with an aneroid barometer. This mechanical instrument is a much better choice than a mercury barometer for use on airplanes. Aneroid barometers (altimeters) are used to indicate altitude in flight. The pressure of the atmosphere is exerted against an thin metal aneroid connected to the pointer. Calibrations are made in thousands of feet rather than in psi or inches of mercury. For example, the standard pressure at sea level is 29.92 "Hg, or 14.7 psi.

At 10 000 feet above sea level, standard pressure is 20.58 "Hg, or 10.10 psi. Altimeters are calibrated so that if the pressure exerted by the atmosphere is 10.10 psi, the altimeter will point to 10 000 ft. (*Figure 2-7*)

BUOYANCY

A solid body submerged in a liquid or a gas weighs less than when weighed in free space. This is because of the upward force, called buoyant force, which any fluid exerts on a body submerged in it. An object will float if this upward force of the fluid is greater than the weight of the object. Objects denser than the fluid, even though they sink readily, appear to lose a part of their weight when submerged. A person can lift a larger weight under water than he or she can possibly lift in the air.

The following experiment is illustrated in *Figure 2-8*. The overflow can is filled to the spout with water. The heavy metal cube is first weighed in still air and weighs 10 lb. It is then weighed while completely submerged in the water and it weighs 3 lb. The difference between the two weights is the buoyant force of the water. As the cube is lowered into the overflow can, the water is caught in the catch bucket. The volume of water which overflows equals the volume of the cube. (The volume of irregular shaped objects can be measured by this method.) If this experiment is performed carefully, the weight of the water displaced by the metal cube exactly equals the buoyant force of the water, which the scale shows to be 7 lb.

Figure 2-6. Atmospheric pressure as inches of mercury.

Figure 2-7. An airplane's altimeter is an aneroid barometer.
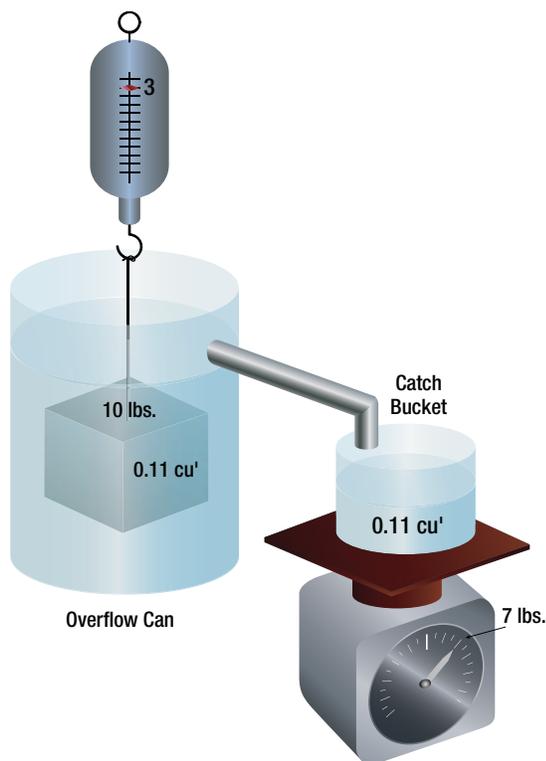
Figure 2-8. Example of buoyancy.

Archimedes (287–212 B.C.) performed similar experiments. As a result, he discovered that the buoyant force which a fluid exerts upon a submerged body is equal to the weight of the fluid the body displaces. This statement is referred to as Archimedes' principle. This principle applies to all fluids, gases as well as liquids. Just as water exerts a buoyant force on submerged objects, air exerts a buoyant force on objects submerged in it.

The amount of buoyant force available to an object can be calculated by using the following formula:

$$\text{Buoyant Force} = \text{Volume of Object} \times \text{Density of Fluid Displaced}$$

If the buoyant force is more than the object weighs, the object will float. If the buoyant force is less than the object weighs, the object will sink. For the object that sinks, its measurable weight will be less by the weight of the displaced fluid.

Example: A 10-ft^3 object weighing 700 lbs is placed in pure water. Will the object float? If the object sinks, what is its measurable weight in the submerged condition? If the object floats, how many cubic feet of its volume is below the water line?

$$\text{Buoyant Force} = \text{Volume of Object} \times \text{Density of Fluid Displaced}$$
$$= 10\,(62.4)$$
$$= 624 \text{ lb}$$

Because the buoyant force is less than the object weighs, the object will sink. The difference between the buoyant force and the object's weight will be its measurable weight, or 76 lb.

Two good examples of buoyancy are a helium filled airship and a seaplane on floats. An airship is able to float in the atmosphere and a seaplane is able to float on water. That means both have more buoyant force than weight. *Figure 2-9* is a DeHavilland Twin Otter seaplane, with a gross takeoff weight of 12 500 lb. At a minimum, the floats on this airplane must be large enough to displace a weight in water equal to the airplane's weight. Certification standards typically require that the floats must be 80 percent larger than the minimum needed to support the airplane.

For this airplane, the necessary size of the floats would be calculated as follows.

Divide the airplane weight by the density of water.
$$12\,500 \div 62.4 = 200.3 \text{ ft}^3$$

Multiply this volume by 80%.
$$200.3 \times 80\% = 160.2 \text{ ft}^3$$

Add the two volumes together to get the total volume of the floats.
$$200.3 + 160.2 = 360.5 \text{ ft}^3$$

Figure 2-9. DeHavilland Twin Otter seaplane.

By looking at the DeHavilland Twin Otter in *Figure 2-9*, it is obvious that much of the volume of the floats is out of the water. This is accomplished by making sure the floats have at least 80 percent more volume than the minimum necessary.

Some of the large Goodyear airships have a volume of 230 000 ft³. Since the fluid they are submerged in is air, to find the buoyant force of the airship, the volume of the airship is multiplied by the density of air (.076 51 lb/ft³). For this Goodyear airship, the buoyant force is 17 597 lb. *Figure 2-10* shows an inside view of the Goodyear airship.

The ballonets, are air chambers within the airship. Through the air scoop, air can be pumped into the ballonets or evacuated from the ballonets in order to control the weight of the airship. Controlling the weight
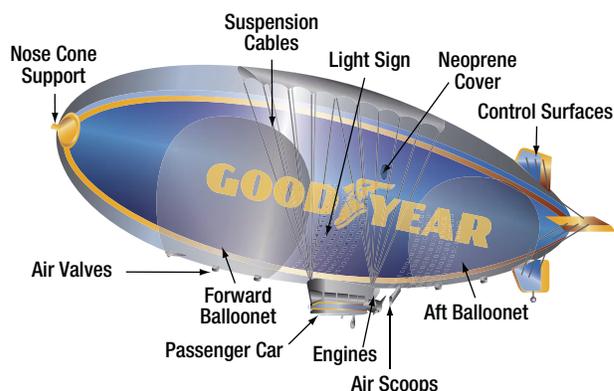
Figure 2-10. Inside view of the Goodyear airship.

of the airship controls how much positive or negative lift it has. Although the airship is classified as a lighter-than-air aircraft, it is in fact flown in a condition slightly heavier than air.

2.2.2 - KINETICS

MOTION
The study of the relationship between the motion of bodies or objects and the forces acting on them is often called the study of "force and motion." In a more specific sense, the relationship between velocity, acceleration, and distance is known as kinematics.

LINEAR MOVEMENT
Motion may be defined as a continuing change of position or place, or as the process in which a body undergoes displacement. When an object is at different points in space at different times, that object is said to be in motion, and if the distance the object moves remains the same for a given period of time, the motion may be described as uniform. Thus, an object in uniform motion always has a constant speed.

SPEED AND VELOCITY
In everyday conversation, speed and velocity are often used as if they mean the same thing. In physics they have definite and distinct meanings. Speed refers to how fast an object is moving, or how far the object will travel in a specific time. The speed of an object tells nothing about the direction an object is moving. For example, if the information is supplied that an airplane leaves New York City and travels 8 hours at a speed of 150 mph, this information tells nothing about the direction in which

the airplane is moving. At the end of 8 hours, it might be in Kansas City, or if it traveled in a circular route, it could be back in New York City.

Velocity is that quantity in physics which denotes both the speed of an object and the direction in which the object moves. Velocity can be defined as the rate of motion in a particular direction. Velocity is also described as being a vector quantity, a vector being a line of specific length, having an arrow on one end or the other. The length of the line indicates the number value and the arrow indicates the direction in which that number is acting.

Two velocity vectors, such as one representing the velocity of an airplane and one representing the velocity of the wind, can be added together in what is called vector analysis. *Figure 2-11* demonstrates this, with vectors "A" and "B" representing the velocity of the airplane and the wind, and vector "C" being the resultant. With no wind, the speed and direction of the airplane would be that shown by vector "A." When accounting for the wind direction and speed, the airplane ends up flying at the speed and direction shown by vector "C."
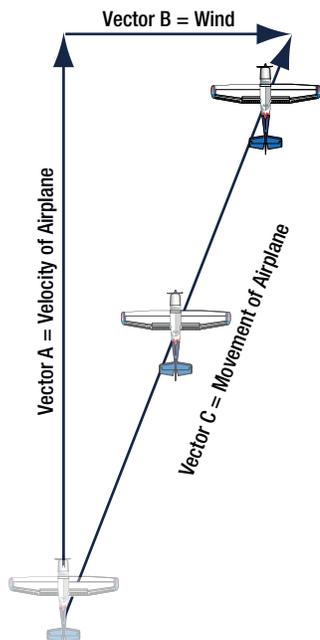
Figure 2-11. Vector analysis for airplane velocity and wind velocity.

Imagine that an airplane is flying in a circular pattern at a constant speed. Because of the circular pattern, the airplane is constantly changing direction, which means the airplane is constantly changing velocity. The reason for this is the fact that velocity includes direction.

To calculate the speed of an object, the distance it travels is divided by the elapsed time. If the distance is measured in miles and the time in hours, the units of speed will be miles per hour (mph). If the distance is measured in feet and the time in seconds, the units of speed will be feet per second (fps). To convert mph to fps, multiply by 1.467. Velocity is calculated the same way, the only difference being it must be recalculated every time the direction changes.

ACCELERATION

Acceleration is defined as the rate of change of velocity. If the velocity of an object is increased from 20 mph to 30 mph, the object has been accelerated. If the increase in velocity is 10 mph in 5 seconds, the rate of change in velocity is 10 mph in 5 seconds, or 2 mph per second. If this were multiplied by 1.467, it could also be expressed as an acceleration of 2.93 feet per second per second (fps/s). By comparison, the acceleration due to gravity is 32.2 fps/s (9.8mps/s). To calculate acceleration, the following formula is used.

$$\text{Acceleration} = \frac{\text{Velocity Final (Vf)} - \text{Velocity Initial (Vi)}}{\text{Time (t)}}$$

Example: An Air Force F-15 fighter is cruising at 400 mph. The pilot advances the throttles to full afterburner and accelerates to 1 200 mph in 20 seconds. What is the average acceleration in mph/s and fps/s?

$$A = \frac{Vf - Vi}{t}$$

$$A = \frac{1\,200 - 400}{20}$$

A = 40 mph/s, or by multiplying by 1.467

A = 58.7 fps/s

In the example just shown, the acceleration was found to be 58.7 fps/s. Since 32.2 fps/s is equal to the acceleration due to gravity, divide the F-15's acceleration by 32.2 to find out how many G forces the pilot is experiencing. In this case, it would be 1.82 Gs.

NEWTON'S LAWS OF MOTION

First law
Objects at rest tend to remain at rest and objects in motion tend to remain in motion at the same speed and in the same direction, unless acted on by an external force.

When a magician snatches a tablecloth from a table and leaves a full setting of dishes undisturbed, he is not displaying a mystic art; he is demonstrating the principle of inertia. Inertia is responsible for the discomfort felt when an airplane is brought to a sudden halt in the parking area and the passengers are thrown forward in their seats. Inertia is a property of matter. This property of matter is described by Newton's first law of motion.

Second Law
When a force acts upon a body, the momentum of that body is changed. The rate of change of momentum is proportional to the applied force.

Bodies in motion have the property called momentum. A body that has great momentum has a strong tendency to remain in motion and is therefore hard to stop. For example, a train moving at even low velocity is difficult to stop because of its large mass. Newton's second law applies to this property. Based on Newton's second law, the formula for calculating thrust is derived, which states that force equals mass times acceleration (F = MA). Earlier in this chapter, it was determined that

mass equals weight divided by gravity, and acceleration equals velocity final minus velocity initial divided by time. Putting all these concepts together, the formula for thrust is:

$$\text{Force} = \frac{\text{Weight (Velocity final – Velocity initial)}}{\text{Gravity (Time)}}$$

$$F = \frac{W\,(Vf - Vi)}{Gt}$$

Example: A turbojet engine is moving 150 lb of air per second through the engine. The air enters going 100 fps and leaves going 1 200 fps. How much thrust, in pounds, is the engine creating?

$$F = \frac{W\,(Vf - Vi)}{Gt}$$

$$F = \frac{150\,(1\,200 - 100)}{32.2\,(1)}$$

$$F = 5\,124 \text{ lb of thrust}$$

Third Law
For every action there is an equal and opposite reaction.

Newton's third law of motion is often called the law of action and reaction. This means that if a force is applied to an object, the object will supply a resistive force exactly equal to and in the opposite direction of the force applied. It is easy to see how this might apply to objects at rest. For example, as a man stands on the floor, the floor exerts a force against his feet exactly equal to his weight. But this law is also applicable when a force is applied to an object in motion.

Forces always occur in pairs. The term *acting force* means the force one body exerts on a second body, and *reacting force* means the force the second body exerts on the first.

When an aircraft propeller pushes a stream of air backward with a force of 500 lbs, the air pushes the blades forward with a force of 500 lbs. This forward force causes the aircraft to move forward. A turbofan engine exerts a force on the air entering the inlet duct, causing it to accelerate out the fan duct and the tailpipe. The air accelerating to the rear is the action, and the force inside the engine that makes it happen is the reaction, also called thrust.

ROTATIONAL MOVEMENT

Circular motion is the motion of an object along a curved path that has a constant radius. For example, if one end of a string is tied to an object and the other end is held in the hand, the object can be swung in a circle. The object is constantly deflected from a straight (linear) path by the pull exerted on the string, as shown in *Figure 2-12*. When the weight is at point A, due to inertia it wants to keep moving in a straight line and end up at point B. Because of the force being exerted on the string, it is forced to move in a circular path and end up at point C.

The string exerts a centripetal force on the object, and the object exerts an equal but opposite force on the string, obeying Newton's third law of motion. The force that is equal to centripetal force, but acting in an opposite direction, is called centrifugal force. Centripetal force is always directly proportional to the mass of the object in circular motion. Thus, if the mass of the object in *Figure 2-12* is doubled, the pull on the string must be doubled to keep the object in its circular path, provided the speed of the object remains constant.

Centripetal force is inversely proportional to the radius of the circle in which an object travels. If the string in *Figure 2-12* is shortened and the speed remains constant, the pull on the string must be increased since the radius is decreased, and the string must pull the object from its linear path more rapidly. Using the same reasoning, the pull on the string must be increased if the object is swung more rapidly in its orbit. Centripetal force is thus directly proportional to the square of the velocity of the object. The formula for centripetal force is:

$$\text{Centripetal Force} = \text{Mass (Velocity}^2) \div \text{Radius}$$
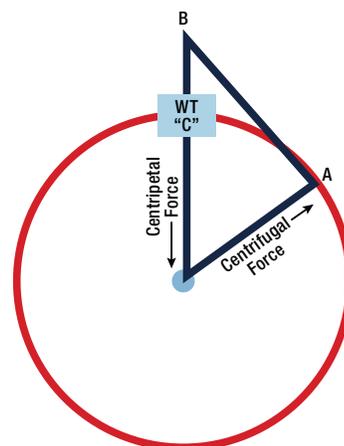
Figure 2-12. Circular motion.

For the formula above, mass would typically be converted to weight divided by gravity, velocity would be in feet per second, and the radius would be in feet.

Example: What would the centripetal force be if a 10 pound weight was moving in a 3ft radius circular path at a velocity of 500 fps?

Centripetal Force = Mass (Velocity²) ÷ Radius

Centripetal Force = $10 (500^2) \div 32.2 (3) = 25\,880$ lb

In the condition identified in the example, the object acts like it weighs 2 588 times more than it actually does. It can also be said that the object is experiencing 2 588 Gs (force of gravity). The fan blades in a large turbofan engine, when the engine is operating at maximum rpm, are experiencing many thousands of Gs for the same reason.

PERIODIC MOVEMENT

PENDULAR MOTION

Periodic motion is evident during pendular motion and vibration. A pendulum is a weight suspended from a fixed point so it can swing freely back and forth. The motion is characterized by a few important variables. The period is the time it takes for the weight to complete one cycle of motion. It is dependent on the length of the suspending rod or string. Specifically, the period varies directly with the square root of "L" which is the length of the suspending item (i.e. a string or rod). The period also varies inversely with the square root of the acceleration of gravity. The following equation expresses these relationships:

$$T = 2\pi\sqrt{\frac{L}{g}}$$

Where:
   T = period in seconds (s)
   L = length of the pendulum in feet or meters
   g = acceleration of gravity (32.2 ft/s² or 9.82 m/s²)

Pendulums are unique in that the period of a pendulum will remain the same as it swings to and fro even though it gradually displaces less and less with each ensuing swing. This regularity has resulted in pendulum motion to be the regulating motion in mechanical clocks.

THEORY OF VIBRATION, HARMONICS, RESONANCE

VIBRATION

Vibration is periodic motion caused by oscillation of the parts of a fluid or an elastic solid whose equilibrium has been disturbed. An electromagnetic wave also experiences vibration. Something that is vibrating has motion back and forth across a central point. While this can be harmless in an aircraft, vibration can also be destructive. Design engineers must design the aircraft to withstand or safely dissipate any vibration produced by the engine, components, or by the aircraft's movement through the atmosphere.

Vibratory motion is also known as harmonic motion. It is regular in nature. Vibration is characterized by having a period, which is the time it takes for a complete cycle of movement. It's frequency is the number of times per second a complete cycle occurs. The unit of measure for frequency is the hertz (Hz). One cycle per second is equal to one hertz. Vibration also has amplitude. Amplitude is measured from the midpoint of the motion to the point of maximum displacement. Unless there is a means to input energy into the vibrating object, the amplitude of vibration will steadily decrease as time goes on. However, the frequency of vibration will remain the same.

On a musical instrument, it is the frequency that sets the pitch of the tone created when the string is plucked. The amplitude is related to the loudness of the vibrating string.

The formula for computing the period of a vibrating or oscillating object is virtually the same as that of a pendulum. Instead of gravity supplying the force as with a pendulum, some other force must be applied to create vibration. But the uniqueness of a steady frequency is shared by vibrating objects and a pendulum. Note that an oscillator in electronics does have a means for steadily supplying extra energy to the vibrating system and does not conform to this model.

$$T = 2\pi\sqrt{\frac{L}{g}}$$

Where:
T = period in seconds (s)
m = mass in pounds or kilograms (kg)
k = force in pound feet or dynes / cm

AIRCRAFT TECHNICAL BOOK COMPANY

HARMONICS

When an object is forced to vibrate at its natural frequencies, it vibrates in a manner such that a standing wave pattern is formed within the object. Whether it is a guitar string, or an air column, the medium vibrates in such a way that a standing wave pattern results.

Each natural frequency that an object or musical instrument produces has its own characteristic vibration pattern. These patterns are created at specific frequencies, which are known as harmonics. For objects that vibrate in regular and periodic fashion, the harmonic frequencies are related to each other by simple whole number ratios. (*Figure 2-13*)

RESONANCE

All types of matter, regardless of whether it is a solid, liquid, or gas, have a natural frequency at which the atoms within that matter vibrate. If two pieces of matter have the same natural frequency, and one of them starts to vibrate, it can transfer its wave energy to the other one and cause it to vibrate. This transfer of energy is known as resonance. Some piston engine powered airplanes have an rpm range that they are placarded to avoid because spinning the prop at that rpm can cause vibration problems. The difficulty lies in the natural frequency of the metal in the prop, and the frequency of vibration that will be set up with a particular tip speed for the prop. At that particular rpm, stresses can be set up that could lead to the propeller coming apart.

VELOCITY RATIO, MECHANICAL ADVANTAGE AND EFFICIENCY

VELOCITY RATIO

Velocity ratio is the ratio of the distance travelled by the effort, compared to the distance travelled by the load in a simple machine. Friction is not included in the computation. As shown in *Figure 2-14*, because of the lever distance between the handle and the wheels, the worker has pulled the handles up a distance of 300mm, causing the wheelbarrow's supporting legs to rise by a distance of 100 mm. Thus, the velocity ratio is measured at 3:1. Similarly, an effort exerted of 100 Newtons for a distance of 300mm equals a result of 300 Newtons moved a distance of 100 mm.

Figure 2-13. The first three levels of harmonic vibration.
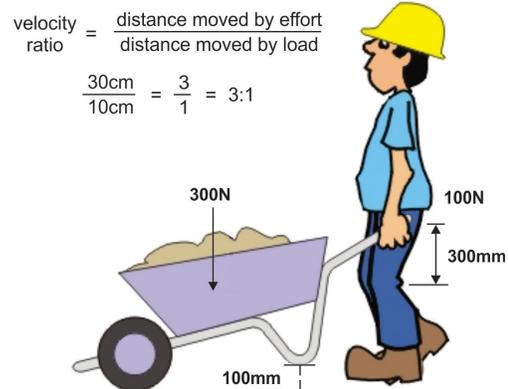
Figure 2-14. A 100 Newton effort over 300mm, yields a 300 Newton result over 100mm.

SIMPLE MACHINE

A machine is any device with which work may be accomplished. In application, machines can be used for any of the following purposes, or combinations of these purposes.

1. Machines are used to transform energy, as in the case of a generator transforming mechanical energy into electrical energy.
2. 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 engine to its propeller.
3. Machines are used 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 that is smaller than the weight of the load.
4. Machines can be used to multiply speed. A good example is the bicycle, by which speed can be gained by exerting a greater force.

5. 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. Physicists, however, recognize only two basic principles in machines: the lever and the inclined plane. The pulley (block and tackle), the wheel and axle, and gears operate on the machine principle of the lever. 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.

MECHANICAL ADVANTAGE

As identified in statements 3 and 4 under simple machines, a machine can be used to multiply force or to multiply speed. It cannot, however, multiply force and speed at the same time. In order to gain one, it must lose the other. To do otherwise would mean the machine has more power going out than coming in, and that is not possible. In reference to machines, mechanical advantage is a comparison of the output force to the input force, or the output distance to the input distance. If there is a mechanical advantage in terms of force, there will be a fractional disadvantage in terms of distance. The following formulas can be used to calculate mechanical advantage.

Mechanical Advantage = Force Out ÷ Force In
or
Mechanical Advantage = Distance Out ÷ Distance In

The Lever

The simplest machine, and perhaps the most familiar one, is the lever. A seesaw is a familiar example of a lever, with two people sitting on either end of a board and a pivoting point in the middle. There are three basic parts in all levers. They are the fulcrum "F," a force or effort "E," and a resistance "R." Shown in *Figure 2-15* are the pivot point "F" (fulcrum), the effort "E" which is applied at a distance "L" from the fulcrum, and a resistance "R" which acts at a distance "l" from the fulcrum. Distances "L" and "l" are the lever arms.

The concept of torque was discussed earlier in this chapter, and torque is very much involved in the operation of a lever. When a person sits on one end of a seesaw, that person applies a downward force in pounds which acts along the distance to the center of the seesaw. This combination of force and distance creates torque, which tries to cause rotation.

First Class Lever

In the first class lever, the fulcrum is located between the effort and the resistance. As mentioned earlier, the seesaw is a good example of a lever, and it happens to be a first class lever. The amount of weight and the distance from the fulcrum can be varied to suit the need. Increasing the distance from the applied effort to the fulcrum, compared to the distance from the fulcrum to the weight being moved, increases the advantage provided by the lever. Crowbars, shears, and pliers are common examples of this class of lever.

The proper balance of an airplane is also a good example, with the center of lift on the wing being the pivot point (fulcrum) and the weight fore and aft of this point being the effort and the resistance. When calculating how much effort is required to lift a specific weight, or how much weight can be lifted by a specific effort, the following formula can be used.

Effort (E) × Effort Arm (L) =
Resistance (R) × Resistance Arm (l)

What this formula really shows is the input torque (effort times effort arm) equals the output torque (resistance times resistance arm). This formula and concept apply to all three classes of levers, and to all simple machines in general.

Example: A first class lever is to be used to lift a 500-lb weight. The distance from the weight to the fulcrum is 12 inches and from the fulcrum to the applied effort is 60 inches. How much force is required to lift the weight?

Effort (E) × Effort Arm (L) =
Resistance (R) × Resistance Arm (l)
E × 60 in = 500 lb × 12 in
E = 500 lb × 12 in ÷ 60 in
E = 100 lb

The mechanical advantage of the lever in this example would be:

Mechanical Advantage = Force Out ÷ Force In
= 500 lb ÷ 100 lb
= 5, or 5 to 1

An interesting thing to note with this example lever is if the applied effort moved down 10 inches, the weight on the other end would only move up 2 inches. The weight being lifted would only move one-fifth as far. The reason for this is the concept of work. Because a lever cannot have more work output than input, if it allows you to lift 5 times more weight, you will only move it ⅕ as far as you move the effort.

Second Class Lever

The second class lever has the fulcrum at one end and the effort is applied at the other end. The resistance is somewhere between these points. A wheelbarrow is a good example of a second class lever, with the wheel at one end being the fulcrum, the handles at the opposite end being the applied effort, and the bucket in the middle being where the weight or resistance is placed. (*Figure 2-16*)

Both first and second class levers are commonly used to help in overcoming big resistances with a relatively small effort. The first class lever, however, is more versatile.

Depending on how close or how far away the weight is placed from the fulcrum, the first class lever can be made to gain force or gain distance, but not both at the same time. The second class lever can only be made to gain force.

Example: The distance from the center of the wheel to the handles on a wheelbarrow is 60 inches. The weight in the bucket is 18 inches from the center of the wheel. If 300 lbs is placed in the bucket, how much force must be applied at the handles to lift the wheelbarrow?

Effort (E) × Effort Arm (L) =
Resistance (R) × Resistance Arm (l)
E × 60 in = 300 lb × 18 in
E = 300 lb × 18 in ÷ 60 in
E = 90 lb
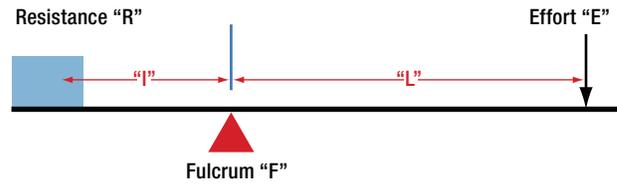
Figure 2-15. First class lever.
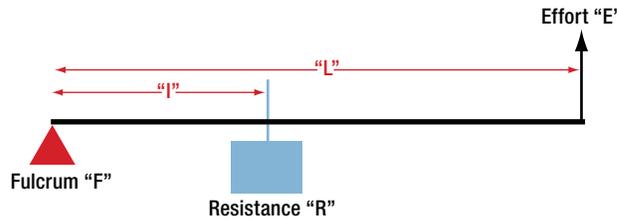
Figure 2-16. Second class lever.

The mechanical advantage of the lever in this example would be:

Mechanical Advantage = Force Out ÷ Force In
= 300 lb ÷ 90 lb
= 3.33, or 3.33 to 1

Third Class Lever

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 help accomplish this are third class levers. As shown in *Figure 2-17*, 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. The retractable main landing gear on an airplane is a good example of a third class lever. The top of the landing gear, where it attaches to the airplane, is the pivot point. The wheel and brake assembly at the bottom of the landing gear is the resistance. The hydraulic actuator that makes the gear retract is attached somewhere in the middle, and that is the applied effort.
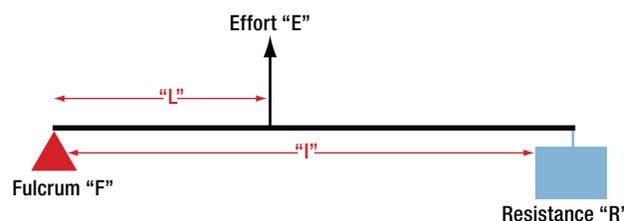
Figure 2-17. Third class lever.

AIRCRAFT
TECHNICAL
BOOK COMPANY

The Pulley

Pulleys are simple machines in the form of a wheel mounted on a fixed axis and supported by a frame. The wheel, or disk, is normally grooved to accommodate a rope. The wheel is sometimes referred to as a "sheave" (sometimes "sheaf"). The frame that supports the wheel is called a block. A block and tackle consists of a pair of blocks. Each block contains one or more pulleys and a rope connecting the pulley(s) of each block.

Single Fixed Pulley

A single fixed pulley is really a first class lever with equal arms. In *Figure 2-18*, the arm from point "R" to point "F" is equal to the arm from point "F" to point "E" (both distances being equal to the radius of the pulley). When a first class lever has equal arms, the mechanical advantage is 1. Thus, the force of the pull on the rope must be equal to the weight of the object being lifted. The only advantage of a single fixed pulley is to change the direction of the force, or pull on the rope.

Single Movable Pulley

A single pulley can be used to magnify the force exerted. In *Figure 2-19*, the pulley is movable, and both ropes extending up from the pulley are sharing in the support of the weight. This single movable pulley acts like a second class lever, with the effort arm (EF) being the diameter of the pulley and the resistance arm (FR) being the radius of the pulley. This type of pulley would have a mechanical advantage of two because the diameter of the pulley is double the radius of the pulley. In use, if someone pulled in 4 ft of the effort rope, the weight would only rise off the floor 2 ft. If the weight was 100 lb, the effort applied would only need to be 50 lb. With this type of pulley, the effort will always be one-half of the weight being lifted.

Block and Tackle

A block and tackle is made up of multiple pulleys, some of them fixed and some movable. In *Figure 2-20*, the block and tackle is made up of four pulleys, the top two being fixed and the bottom two being movable. Viewing the figure from right to left, notice there are four ropes supporting the weight and a fifth rope where the effort is applied. The number of weight supporting ropes determines the mechanical advantage of a block and tackle, so in this case the mechanical advantage is four. If the weight was 200 lbs, it would require a 50 lb effort to lift it.
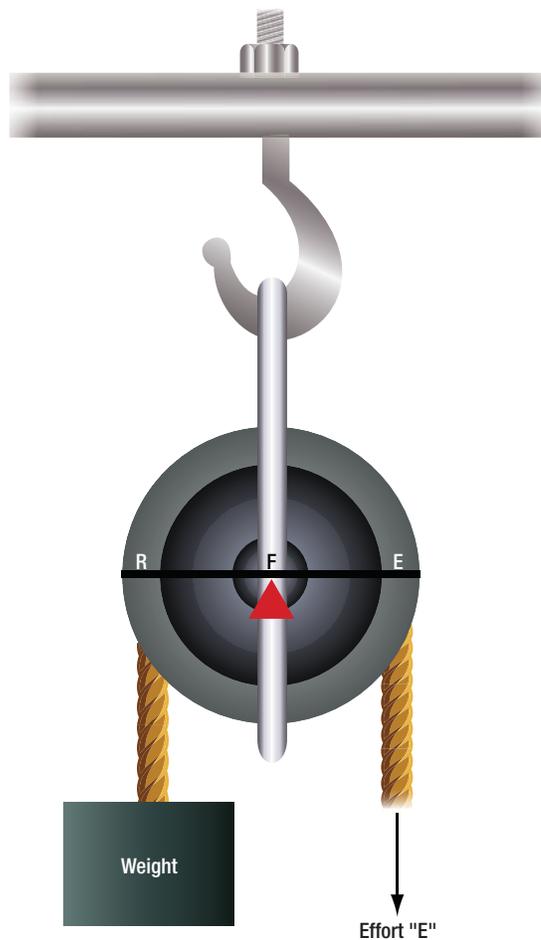
Figure 2-18. Single fixed pulley.

The Gear

Two gears with teeth on their outer edges, as shown in *Figure 2-21*, act like a first class lever when one gear drives the other. The gear with the input force is called the drive gear, and the other is called the driven gear. The effort arm is the diameter of the driven gear, and the resistance arm is the diameter of the drive gear. Notice that the two gears turn in opposite directions (the bottom one clockwise and the top one counterclockwise). The gear on top (yellow) is 9 inches in diameter and has 45 teeth, and the gear on the bottom (blue) is 12 inches in diameter and has 60 teeth.

Imagine that the blue gear is driving the yellow one (blue is the drive, yellow is the driven). The mechanical advantage in terms of force would be the effort arm divided by the resistance arm, or 9 ÷ 12, which is 0.75. This would actually be called a fractional disadvantage, because there would be less force out than force in. The mechanical advantage in terms of distance (rpm in this case), would be 12 ÷ 9, or 1.33.
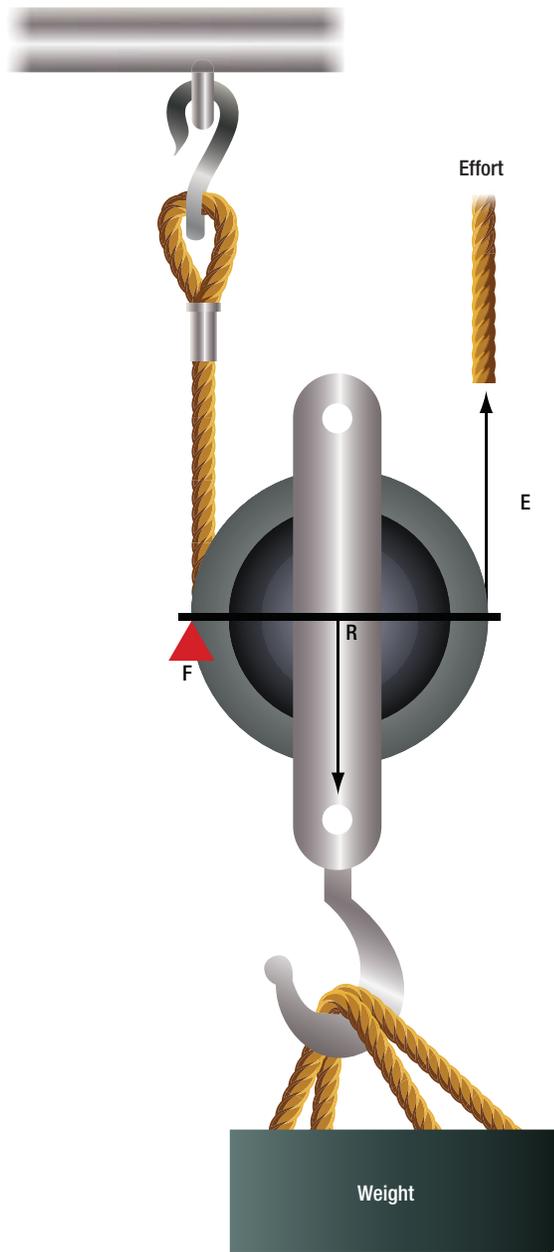
Figure 2-19. Single movable pulley.
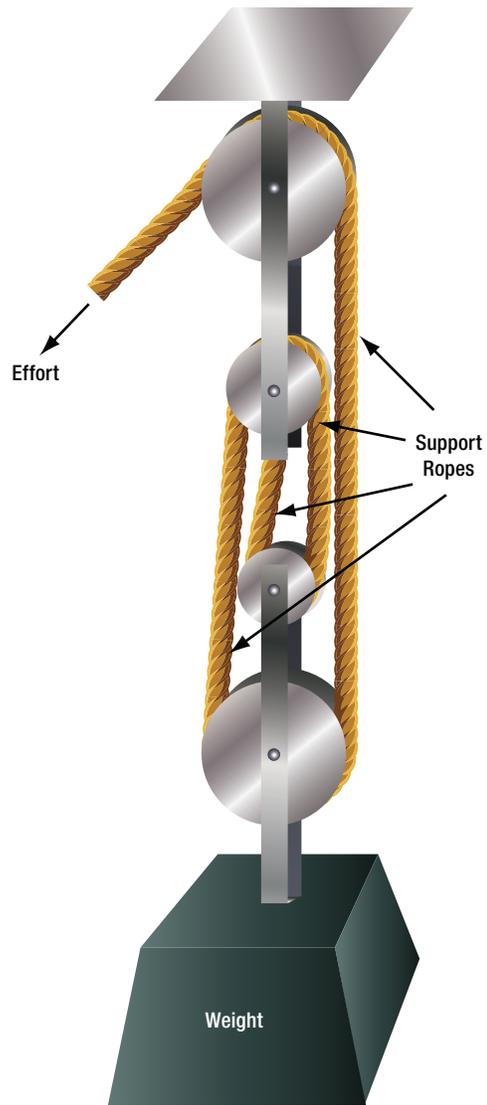
Figure 2-20. Block and tackle.

Figure 2-21. Spur gears.

This analysis tells us that when a large gear drives a small one, the small one turns faster and has less available force. In order to be a force gaining machine, the small gear needs to turn the large one. When the terminology reduction gearbox is used, such as a propeller reduction gearbox, it means that there is more rpm going in than is coming out. The end result is an increase in force, and ultimately torque.

Bevel gears are used to change the plane of rotation, so that a shaft turning horizontally can make a vertical shaft rotate. The size of the gears and their number of teeth determine the mechanical advantage, and whether

force is being increased or rpm is being increased. If each gear has the same number of teeth, there would be no change in force or rpm. (***Figure 2–22***)

The worm gear has an extremely high mechanical advantage. The input force goes into the spiral worm gear, which drives the spur gear. One complete revolution of the worm gear only makes the spur gear turn an amount equal to one tooth. The mechanical advantage is equal to the number of teeth on the spur gear, which in this case is 25. This is a force gaining machine, to the tune of 25 times more output force. (***Figure 2–23***)

The planetary sun gear system is typical of what would be found in a propeller reduction gearbox. The power output shaft of the engine would drive the sun gear in the middle, which rotates the planetary gears and ultimately the ring gear. In this example, the sun gear has 28 teeth, each planet gear has 22 teeth, and the ring gear has 82 teeth. To figure out how much gear reduction is taking place, the number of teeth on the ring gear is divided by the number of teeth on the sun gear. In this case, the gear reduction is 2.93, meaning the engine has an rpm 2.93 times greater than the propeller. (***Figure 2–24***)

Gear Ratio
The velocity ratio and the gear ratio of a geared drive are essentially the same thing. A gear ratio is calculated by comparing the number of teeth on a drive gear to the number of teeth on the driven gear. The result is a ratio that brings into focus the amount of mechanical advantage produced by the assembly.

A speed ratio or velocity ratio can also be calculated. Instead of comparing the number of teeth on the gears, the rotational speed of each gear is considered.

When two gears are used in an aircraft component, the rotational speed of each gear is represented as a speed ratio. As the number of teeth in a gear decreases, the rotational speed of that gear increases, and vice-versa. Therefore, the speed ratio of two gears is the inverse (or opposite) of the gear ratio. If two gears have a gear ratio of 2:9, then their speed ratio is 9:2.

Example: A pinion gear with 10 teeth is driving a spur gear with 40 teeth. The spur gear is rotating at 160 rpm. Determine the speed of the pinion gear.
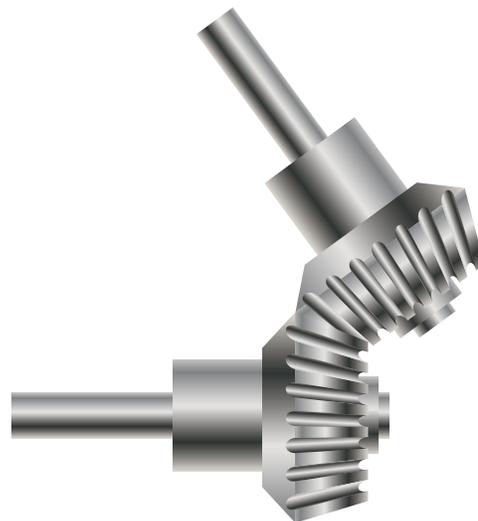
Figure 2-22. Bevel gears.
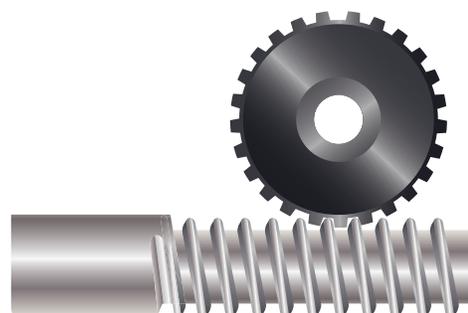
Figure 2-23. Worm gear.
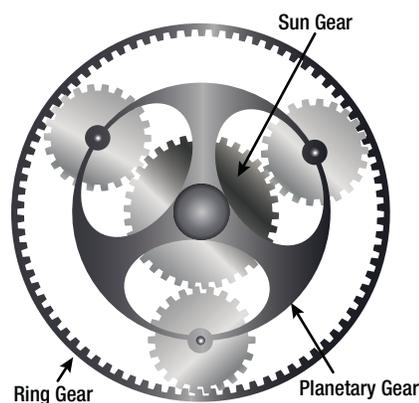
Figure 2-24. Planetary sun gear.

$$\frac{\text{Teeth in Pinion Gear}}{\text{Teeth in Spur Gear}} = \frac{\text{Speed of Spur Gear}}{\text{Speed of Pinion Gear}}$$

$$\frac{10 \text{ Teeth}}{40 \text{ Teeth}} = \frac{160 \text{ rpm}}{\text{Sp(speed of pinion gear)}}$$

To solve for SP, multiply 40 × 160, then divide by 10. The speed of the pinion gear is 640 rpm.

Example: If the cruising speed of an airplane is 200 knots and its maximum speed is 250 knots, what is the ratio of cruising speed to maximum speed?

First, express the cruising speed as the numerator of a fraction whose denominator is the maximum speed.

$$\text{Ratio} = \frac{200}{250}$$

Next, reduce the resulting fraction to its lowest terms.

$$\text{Ratio} = \frac{200}{250} = \frac{4}{5}$$

The ratio of cruising speed to maximum speed is 4:5.

Another common use of ratios is to convert any given ratio to an equivalent ratio with a denominator of 1. Example: Express the ratio 9:5 as a ratio with a denominator of 1.

$$R = \frac{9}{5} = \frac{?}{1} \text{ Since } 9 \div 5 = 1.8, \text{ then } \frac{9}{5} = \frac{1.8}{1}$$

Therefore, 9:5 is the same ratio as 1.8:1. In other words, 9 to 5 is the same ratio as 1.8 to 1.

Inclined Plane

The inclined plane is a simple machine that facilitates the raising or lowering of heavy objects by application of a small force over a relatively long distance. Some familiar examples of the inclined plane are mountain highways and a loading ramp on the back of a truck. When weighing a small airplane, like a Cessna 172, an inclined plane (ramp) can be used to get the airplane on the scales by pushing it, rather than jacking it. A ramp can be seen in *Figure 2-25*, where a Cessna 172 right

main gear is sitting on an electronic scale. The airplane was pushed up the ramps to get it on the scales.

With an inclined plane, the length of the incline is the effort arm and the vertical height of the incline is the resistance arm. If the length of the incline is five times greater than the height, there will be a force advantage, or mechanical advantage, of five. The Cessna 172 in *Figure 2-25* weighed 1 600 lb on the day of the weighing. The ramp it is sitting on is 6 inches tall (resistance arm) and the length of the ramp is 24 inches (effort arm).

To calculate the force needed to push the airplane up the ramps, use the same formula introduced earlier when levers were discussed, as follows:

$$\text{Effort (E)} \times \text{Effort Arm (L)} =$$
$$\text{Resistance (R)} \times \text{Resistance Arm (l)}$$
$$\text{E} \times 24 \text{ in} = 1\,600 \text{ lb} \times 6 \text{ in}$$
$$\text{E} = 600 \text{ lb} \times 6 \text{ in} \div 24 \text{ in}$$
$$\text{E} = 400 \text{ lb}$$

Bolts, screws, and wedges are also examples of devices that operate on the principle of the inclined plane. A bolt, for example, has a spiral thread that runs around its circumference. As the thread winds around the bolt's circumference, it moves a vertical distance equal to the space between the threads. The circumference of the bolt is the effort arm and the distance between the threads is the resistance arm. (*Figure 2-26*)

Based on this analysis, it can be seen that a fine threaded bolt (more threads per inch) has a greater mechanical advantage than a coarse threaded bolt.

Figure 2-25. Ramp in use with a Cessna 172.

Figure 2-26. A bolt and nut as an inclined plane.

The Wedge

The Wedge

A chisel is a good example of a wedge. A chisel might be 8 inches long and only ½ inch wide, with a sharp tip and tapered sides. The 8-inch length is the effort arm and the ½-inch width is the resistance arm. This chisel would provide a force advantage (mechanical advantage) of 16.

EFFICIENCY

Mechanical efficiency is always a goal of the aircraft designer. Efficiency refers to how well a machine uses input energy. Losses due to heat, friction, deflection and wear cause a machine to be inefficient. A machine that minimizes these losses in said to be efficient.

Efficiency is measured in percentage. No machine can be 100% efficient. A way to calculate efficiency is with the following equation:

Efficiency = Mechanical Advantage ÷ Speed Ratio × 100

Another way to look at efficiency is as follows:

Efficiency = Measured Performance ÷ Ideal Performance

In the next section of this sub-module, force, work and one of the major factors that causes machines to not be efficient, friction, are examined.

2.2.3 - DYNAMICS

(A) MASS AND WEIGHT

Mass is a measure of the quantity of matter in an object. In other words, how many molecules are in the object, or how many atoms, or to be more specific, how many protons, neutrons, and electrons. The mass of an object does not change regardless of where you take it in the universe, and it does not change with a change of state. The only way to change the mass of an object is to add or take away atoms.

Mathematically, mass can be stated as follows:

Mass = Weight ÷ Acceleration due to gravity

The acceleration due to gravity here on earth is 32.2 feet per second per second (32.2 fps/s). An object weighing 32.2 pounds (lbs) here on earth is said to have a mass of 1 slug. A slug is a quantity of mass that will accelerate at a rate of 1 ft/s² when a force of 1 pound is applied. In other words, under standard atmospheric conditions (gravity equal to 32.2) a mass of one slug is equal to 32.2 lb.

Weight is a measure of the pull of gravity acting on the mass of an object. The more mass an object has, the more it will weigh under the earth's force of gravity. Because it is not possible for the mass of an object to go away, the only way for an object to be weightless is for gravity to go away.

We view astronauts on the space shuttle and it appears that they are weightless. Even though the shuttle is quite a few miles above the surface of the earth, the force of gravity has not gone away, and the astronauts are not weightless. The astronauts and the space shuttle are in a state of free fall, so relative to the shuttle the astronauts appear to be weightless.

Mathematically, weight can be stated as follows:

Weight = Mass × Gravity

FORCE

Before the concept of work, power, or torque can be discussed, we must understand what force means. Force is the intensity of an impetus, or the intensity of an input. For example, if we apply a force to an object, the tendency will be for the object to move. Another way to look at it is that for work, power, or torque to exist, there has to be a force that initiates the process.

The unit for force in the English system of measurement is pounds, and in the metric system it is newtons. One pound of force is equal to 4.448 newtons. When we calculate the thrust of a turbine engine, we use the formula "Force = Mass × Acceleration," and the thrust of the engine is expressed in pounds. The GE90-115 turbofan engine (powerplant for the Boeing 777-300), for example, has 115 000 pounds of thrust.

INERTIA

Inertia is the resistance of an object to a change in its state of motion, including changes to its speed or direction. Inertia tends to keep an object moving in a straight line and a constant velocity. Similarly, inertia

AIRCRAFT TECHNICAL BOOK COMPANY

is the property, which needs to be overcome before a stationary object may begin to move from its present position. Thus, an object will continue moving at its current velocity until some force causes its speed or direction to change. (**Figure 2-27**)

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 in the mechanical sense of the term, 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.

To calculate work, the following formula is used:

$$Work = Force\ (F) \times Distance\ (d)$$

In the imperial system, the force will be identified in pounds and the distance either in feet or inches, so the units will be foot-pounds or inch-pounds. Notice these are the same units that were used for potential and kinetic energy.

In the SI/Metric System, the force is identified in newtons (N) and the distance in meters, with the resultant units being joules. One pound of force is equal to 4.448 N and one meter is equal to 3.28 feet. One joule is equal to 1.36 ft-lb.

Example: How much work is accomplished by jacking a 150 000-lb Airbus A-320 airplane a vertical height of 3 ft? (**Figure 2-28**)

$$
\begin{aligned}
Work &= Force\ (F) \times Distance\ (d) \\
&= 150\ 000\ lb \times 4\ ft \\
&= 600\ 000\ ft\text{-}lb
\end{aligned}
$$

Example: How much work is accomplished when a tow
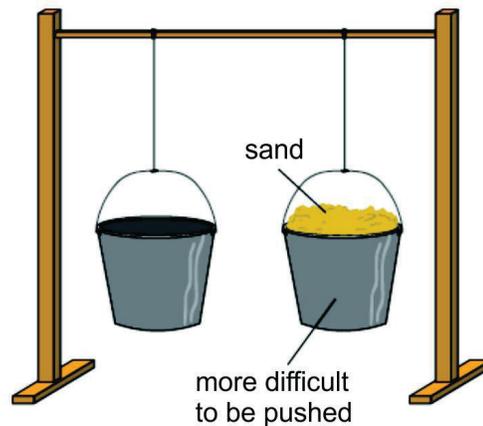
Figure 2-27. An object of greater mass has more inertia than a lesser object.

Figure 2-28. Airbus A-320 being jacked.

tractor is hooked up to a tow bar and a Boeing 737-800 airplane weighing 130 000 lbs is pushed 80 ft into the hangar? The force on the tow bar is 5 000 lb.

In this last example, notice the force does not equal the weight of the airplane. This is because the airplane is being moved horizontally and not lifted vertically. In virtually all cases, it takes less work to move something horizontally than it does to lift it vertically. Most people can push their car a short distance if it runs out of gas, but they cannot get under their car and lift it off the ground.

Power

The concept of power involves the previously discussed topic of work, which was a force being applied over a measured distance, but adds one more consideration: time. In other words, how long does it take to accomplish the work. If someone asked the average person if he or she could lift one million pounds 5 feet off the ground, the answer most assuredly would be no. This person

AIRCRAFT
TECHNICAL
BOOK COMPANY

would probably assume that he or she is to lift it all at once. What if he or she is given 365 days to lift it, and could lift small amounts of weight at a time? The work involved would be the same, regardless of how long it took to lift the weight, but the power required is different. If the weight is to be lifted in a shorter period of time, it will take more power.

The formula for power is as follows:

$$Power = Force \times Distance \div Time$$

The units for power will be foot-pounds per minute, foot-pounds per second, inch-pounds per minute or second, and possibly mile-pounds per hour. The units depend on how distance and time are measured.

Many years ago there was a desire to compare the power of the newly evolving steam engine to that of horses. People wanted to know how many horses the steam engine was equivalent to. Because of this, the value we currently know as one horsepower (hp) was developed, and it is equal to 550 foot-pounds per second (ft-lb/s). It was found that the average horse could lift a weight of 550 lbs, one foot off the ground, in one second. The values we use today, in order to convert power to horsepower, are as follows:

> 1 hp = 550 ft-lb/s
> 1 hp = 33 000 ft-lb/min.
> 1 hp = 375 mile pounds per hour (mi-lb/hr)
> 1 hp = 746 watts (electricity conversion)

To convert power to horsepower, divide the power by the appropriate conversion based on the units being used.

Example: What power would be needed, and also horsepower, to raise the GE-90 turbofan engine into position to install it on a Boeing 777-300 airplane? The engine weighs 19 000 lbs and it must be lifted 4 ft in 2 minutes.

> Power = Force × distance ÷ time
>   = 19 000 lbs × 4 ft ÷ 2 min.
>   = 38 000 ft-lb/min.
> Hp = 38 000 ft-lb/min. ÷ 33 000 ft-lb/min
> Hp = 1.15

The hoist that will be used to raise this engine into position will need to be powered by an electric motor because the average person will not be able to generate 1.15 hp in their arms for the necessary 2 minutes.

Torque

Torque is a very interesting concept and occurrence, and it is definitely something that needs to be discussed in conjunction with work and power. Whereas work is described as a force acting through a distance, torque is described as a force acting along a distance. Torque is something that creates twisting and tries to make something rotate.

If we push on an object with a force of 10 lb and it moves 10 inches in a straight line, we have done 100 in-lb of work. By comparison, if we have a wrench 10 inches long that is on a bolt, and we push down on it with a force of 10 lbs, a torque of 100 in-lb is applied to the bolt. If the bolt was already tight and did not move as we pushed down on the wrench, the torque of 100 in-lb would still exist.

The formula for torque is:

$$Torque = Force \times Distance$$

Even though the formula looks the same as the one for calculating work, recognize that the distance value in this formula is not the linear distance an object moves, but rather the distance along which the force is applied.

Notice that with torque nothing had to move, because the force is being applied along a distance and not through a distance. Notice also that although the units of work and torque appear to be the same, they are not. The units of work were inch-pounds and the units of torque were pound-inches, and that is what differentiates the two.

Torque is very important when thinking about how engines work, both piston engines and gas turbine engines. Both types of engines create torque in advance of being able to create work or power. With a piston engine, a force in pounds pushes down on the top of the piston and tries to make it move. The piston is attached to the connecting rod, which is attached to the crankshaft at an offset. That offset would be like the length of the wrench discussed earlier, and the force acting along that length is what creates torque. (*Figure 2-29*)

For the cylinder in *Figure 2-29*, there is a force of 500 lbs pushing down on the top of the piston. The connecting rod attaches to the crankshaft at an offset distance of 4 in. The product of the force and the offset distance is the torque, in this case 2 000 in-lb.

In a turbine engine, the turbine blades at the back of the engine extract energy from the high velocity exhaust gases. The energy extracted becomes a force in pounds pushing on the turbine blades, which happen to be a certain number of inches from the center of the shaft they are trying to make rotate. The number of inches from the turbine blades to the center of the shaft would be like the length of the wrench discussed earlier.

Mathematically, there is a relationship between the horsepower of an engine and the torque of an engine.

The formula that shows this relationship is as follows:

$$Torque = Horsepower \times 5\ 252 \div rpm$$

Torque = F × d
Torque = 500 × 4
Torque = 2 000 lb.-in.
Torque = 166.7 lb.-ft.

Force of 500 lb.

Piston

Connecting Rod

Crankshaft

4"
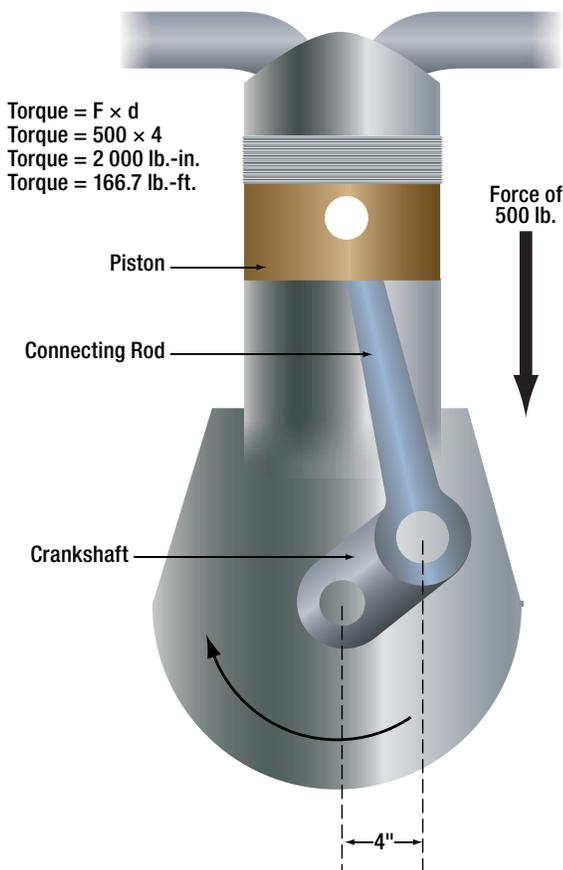
Figure 2-29. Piston engine and torque.

Example: A Cessna 172R has a Lycoming IO-360 engine that creates 180 horsepower at 2 700 rpm. How many pound-feet of torque is the engine producing?

$$Torque = 180 \times 5\ 252 \div 2\ 700 = 350\ lb\text{-}ft$$

ENERGY

Energy is typically defined as something that gives us the capacity to perform work. As individuals, saying that we feel full of energy is probably indicating that we can perform a lot of work. Energy can be classified as one of two types: either potential or kinetic.

Potential Energy

Potential energy is defined as being energy at rest, or energy that is stored. Potential energy may be classified into three groups: (1) that due to position, (2) that due to distortion of an elastic body, and (3) that which produces work through chemical action. Water in an elevated reservoir, and an airplane raised off the ground sitting on jacks are examples of the first group; a stretched bungee chord on a Piper Tri-Pacer or compressed spring are examples of the second group; and energy in aviation gasoline, food, and storage batteries are examples of the third group.

To calculate the potential energy of an object due to its position, as in height, the following formula is used:

$$Potential\ Energy = Weight \times Height$$

A calculation based on this formula will produce an answer that has units of foot-pounds (ft-lbs) or inch-pounds (in-lbs), which are the same units that apply to work. Work, which is covered later in this *Sub-Module*, is described as a force being applied over a measured distance, with the force being pounds and the distance being feet or inches. It can be seen that potential energy and work have a lot in common.

Example: A Boeing 747 weighing 450 000 pounds needs to be raised 4 feet in the air so maintenance can be done on the landing gear. How much potential energy does the airplane possess because of this raised position?

$$Potential\ Energy = Weight \times Height$$
$$PE = 450\ 000\ lb \times 4\ ft$$
$$PE = 1\ 800\ 000\ ft\text{-}lb$$

AIRCRAFT
TECHNICAL
BOOK COMPANY

As mentioned previously, aviation gasoline possesses potential energy because of its chemical nature. Gasoline has the potential to release heat energy, based on its British thermal unit (BTU) content. One pound of aviation gas contains 18 900 BTU of heat energy, and each BTU is capable of 778 ft-lbs of work. So if we multiply 778 by 18 900, we find that one pound of aviation gas is capable of 14 704 200 ft-lbs of work. Imagine the potential energy in the completely serviced fuel tanks of an airplane.

Kinetic Energy
Kinetic energy is defined as being energy in motion. An airplane rolling down the runway or a rotating flywheel on an engine are both examples of kinetic energy. Kinetic energy has the same units as potential energy, namely foot-pounds or inch-pounds. To calculate the kinetic energy for something in motion, the following formula is used:

$$\text{Kinetic Energy} = \tfrac{1}{2}\ \text{Mass} \times \text{Velocity}^2$$

To use the formula, we will show the mass as weight ÷ gravity and the velocity of the object will be in feet per second. This is necessary to end up with units in foot pounds.

Example: A Boeing 777 weighing 600 000 lbs is moving down the runway on its takeoff roll with a velocity of 200 fps. How many foot-pounds of kinetic energy does the airplane possess? (*Figure 2-30*)

$$\text{Kinetic Energy} = \tfrac{1}{2}\ \text{Mass} \times \text{Velocity}^2$$
$$\text{Kinetic Energy} = \tfrac{1}{2} \times 600\ 000 \div 32.2 \times 200^2$$
$$\text{KE} = 372\ 670\ 000\ \text{ft-lb}$$

Figure 2-30. Kinetic energy (Boeing 777 taking off).

Total Energy
As already mentioned, the mechanical energy of an object can be the result of its motion (kinetic energy) and/or its stored energy of position (potential energy). The total amount of mechanical energy is simply the sum of the potential and kinetic energy.

HEAT AND EFFICIENCY
As stated previously, mechanical efficiency requires the actual performance of a machine to be as close as possible to the ideal performance of that machine. In addition to frictional losses, many machines fail to convert some of the input energy to output due to heat loss. An engine, for example, loses significant heat energy through conduction to the various parts of the engine. Not only does the combustion of the fuel need to be maximized, transfer of the energy released must occur with the least amount of heat loss. This is a significant task for a heat engine because the engine, which is turning due to heat energy from combustion, is always cooler than the heat of combustion and will constantly act as a heat sink. The most efficient heat engines operate at around 50% efficiency with the average engine operating at 25-35% efficiency.

(B) MOMENTUM
Newton's third law, *"for every action there is an equal and opposite reaction"*, is most often associated with the forces involved in jet engine thrust. It also applies to momentum and the action of objects that are interacting. There is always an equal force in the opposite direction when one object acts upon another. So if Object 1 were to collide with a second object, first we know that Object 2 will exert an opposing force on Object 1. And, the momentum of the objects will be affected by the applied force because force affects acceleration (Force = Mass × Acceleration) and acceleration affects momentum (Momentum = Mass × Velocity). Thus, the force on both objects will be equal but their accelerations will be affected differently in relation to their masses.

Conservation Of Momentum
In the above paragraph, even if Object 2 is stationary when Object 1 applies a force to it, Object 2 will begin to accelerate thus giving it momentum. Object 1 already had momentum which is affected by its interaction with Object 2. In this and all other similar cases, momentum is conserved. The momentum of each object changes but the total momentum of both objects remains the same.

Object 2 will accelerate and Object 1 will decelerate but the total momentum of both objects remains the same. This is the momentum conservation principle.

Impulse

In physics, Force × time is known as impulse. Impulse = change in momentum. Consider the following equations to see how this is true.

$$\text{Force} = \text{Mass} \times \text{Acceleration and,}$$

$$\text{Acceleration} = \frac{\text{Change in Velocity}}{\text{time}}$$

Therefore, by substitution:

$$\text{Force} = \text{Mass} \times \frac{\text{Change in Velocity}}{\text{time}}$$

Using symbols, this is: $F = M \times \frac{\Delta V}{t}$

By multiplying both sides of the equation by t:

$$F \times t = M \times \Delta V, \text{ or, as stated above, by definition:}$$
$$\text{Impulse} = M \times \Delta V$$

By definition: Momentum = Mass × Velocity.

Therefore it is logical to realize that:

$$\text{Mass} \times \Delta\text{Velocity} = \Delta\text{Momentum}$$

So, Impulse = Change in momentum.

Thus, in a collision, for example, a force is applied for a certain amount of time and the object will experience a change in momentum. That is, the impulse experienced causes a change in the momentum of the object. But if both colliding objects are considered. The total momentum of both objects remains the same.

GYROSCOPIC PRINCIPLES

Gyroscopes and the gyroscopic effect play a large role in aviation - from the propeller's effects on the behavior of the aircraft to the use of gyroscopes in instruments. An understanding of basic gyroscopic principles is given in this section.

A mechanical gyroscope, or gyro, is comprised of a wheel or rotor with its mass concentrated around its perimeter. The rotor has bearings to enable it to spin at high speeds. (*Figure 2-31A*) Different mounting configurations are available for the rotor and axle, which allow the rotor assembly to rotate about one or two axes perpendicular to its axis of spin. To suspend the rotor for rotation, the axle is first mounted in a supporting ring. (*Figure 2-31B*)

If brackets are attached 90° around the supporting ring from where the spin axle attached, the supporting ring and rotor can both move freely 360°. When in this configuration, the gyro is said to be a captive gyro. It can rotate about only one axis that is perpendicular to the axis of spin. (*Figure 2-31C*)
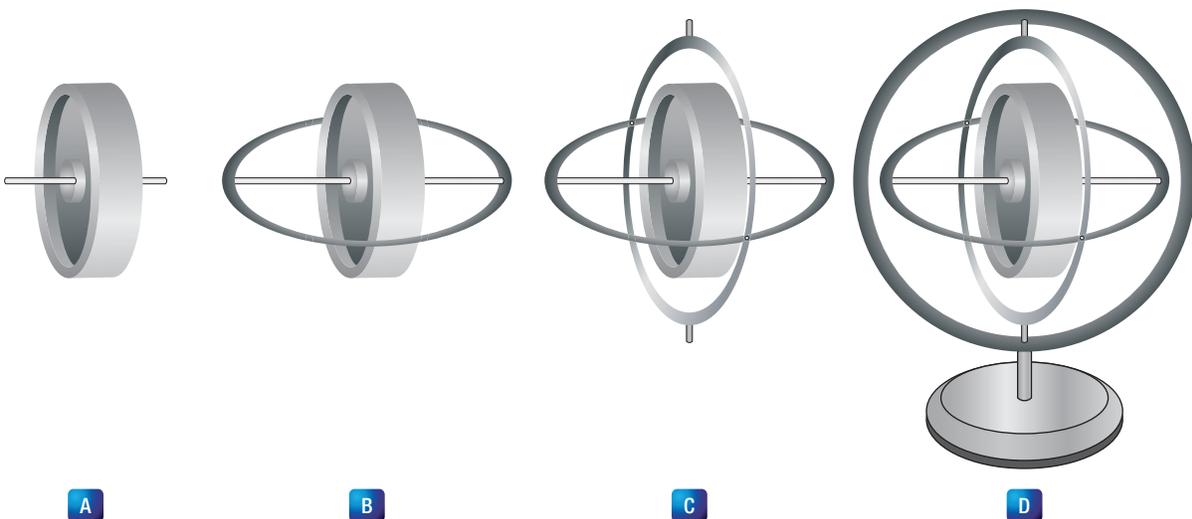
Figure 2-31. Gyroscopes.

The supporting ring can also be mounted inside an outer ring. The bearing points are the same as the bracket just described, 90° around the supporting ring from where the spin axle attached. Attachment of a bracket to this outer ring allows the rotor to rotate in two planes while spinning. Both of these are perpendicular to the spin axis of the rotor. The plane that the rotor spins in due to its rotation about its axle is not counted as a plane of rotation.

A gyroscope with this configuration, two rings plus the mounting bracket, is said to be a free gyro because it is free to rotate about two axes that are both perpendicular to the rotor's spin axis. (*Figure 2-31D*) As a result, the supporting ring with spinning gyro mounted inside is free to turn 360° inside the outer ring.

Unless the rotor of a gyro is spinning, it has no unusual properties; it is simply a wheel universally mounted. When the rotor is rotated at a high speed and due to its inertia, the gyro exhibits a couple of unique characteristics. The first is called gyroscopic rigidity, or rigidity in space. This means that the rotor of a free gyro always points in the same direction no matter which way the base of the gyro is positioned. (*Figure 2-32*)

Gyroscopic rigidity depends upon several design factors:
1. Weight: For a given size, a heavy mass is more resistant to disturbing forces than a light mass.
1. Angular velocity: The higher the rotational speed, the greater the rigidity or resistance is to deflection.
1. Radius at which the weight is concentrated: Maximum effect is obtained from a mass when its principal weight is concentrated near the rim, rotating at high speed.
1. Bearing friction: Any friction applies a deflecting force to a gyro minimizing bearing friction keeps deflecting forces at a minimum.

This characteristic of gyros to remain rigid in space is exploited in the attitude-indicating instruments and the directional indicators that use gyros.

Precession is a second important characteristic of gyroscopes. By applying a force to the horizontal axis of the gyro, a unique phenomenon occurs. The applied force is resisted. Instead of responding to the force by moving about the horizontal axis, the gyro moves in response about its vertical axis. Stated another way, an applied force to the axis of the spinning gyro does not cause the axis to tilt. Rather, the gyro responds as though the force was applied 90° around in the direction of rotation of the gyro rotor. The gyro rotates rather than tilts. (*Figure 2-33*)

This predictable controlled precession of a gyroscope is utilized in a turn and bank instrument. The rigidity in space and precession characteristics of gyroscopic action must always be considered when objects of any appreciable mass are rotating.
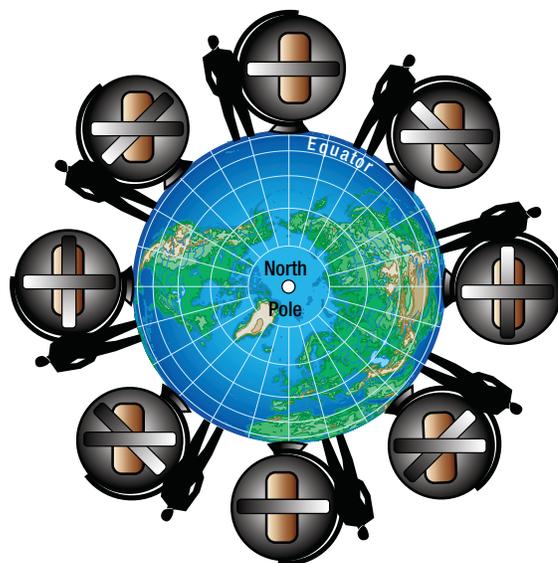
Figure 2-32. Once spinning, a free gyro rotor stays oriented in the same position in space despite the position or location of its base.
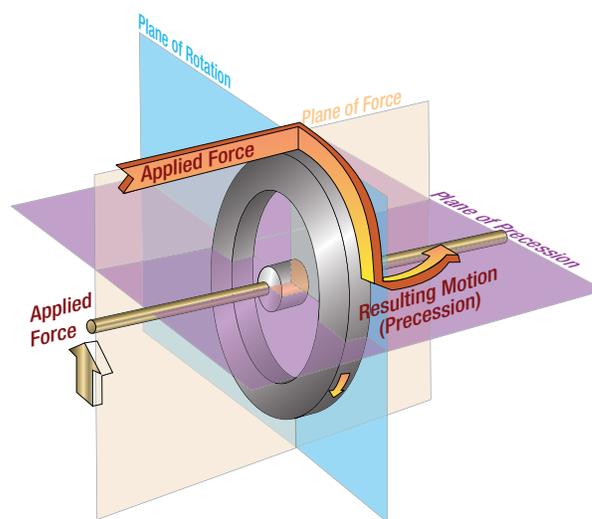
Figure 2-33. When a force is applied to a spinning gyroscope, it reacts as though the force came from 90° further around the rotor in the direction it is spinning. The plane of the applied force, the plane of the rotation, and the plane in which the gyro responds (known as the plane of precession), are all perpendicular to each other.

FRICTION

In calculating work done, the actual resistance to be overcome is measured. This is not necessarily the weight of the object being moved. (*Figure 2-34*) A 900 lb load is being pulled a distance of 200 ft. This does not mean that the work done (force × distance) is 180 000 ft-lbs (900 lb × 200 ft). This is because the person pulling the load is not working against the total weight of the load, but rather against the rolling friction of the cart, which may be no more than 90 lbs.

Friction is an important aspect of work. Without friction it would be impossible to walk. One would have to shove oneself from place to place, and would have to bump against some obstacle to stop at a destination. Yet friction is a liability as well as an asset and requires consideration when dealing with any moving mechanism.

In experiments relating to friction, measurement of the applied forces reveals that there are three kinds of friction. One force is required to start a body moving, while another is required to keep the body moving at constant speed. Also, after a body is in motion, a definitely larger force is required to keep it sliding than to keep it rolling. Thus, the three kinds of friction may be classified as:
1. Starting (static) friction
2. Sliding friction, and
3. Rolling friction.

Static Friction

When an attempt is made to slide a heavy object along a surface, the object must first be broken loose or started. Once in motion, it slides more easily. The "breaking loose" force is, of course, proportional to the weight of the body. The force necessary to start the body moving slowly is designated "F". This is the normal force pressing the body against the surface (usually its weight). Since the nature of the surfaces rubbing against each other is important, they must be considered. The nature of the surfaces is indicated by the coefficient of starting friction which is designated by the letter "k." This coefficient can be established for various materials and is often published in tabular form. Thus, when the load (weight of the object) is known, starting friction can be calculated by using the following formula:

$$F = kF'$$

Figure 2-34. The effect of friction on work.

For example, if the coefficient of sliding friction of a smooth iron block on a smooth, horizontal surface is 0.3, the force required to start a 10 lb block would be 3 lbs; a 40-lb block, 12 lbs.

Starting friction for objects equipped with wheels and roller bearings is much smaller than that for sliding objects. Nevertheless, a locomotive would have difficulty getting a long train of cars in motion all at one time. Therefore, the couples between the cars are purposely made to have a few inches of play. When starting the train, the engineer backs the engine until all the cars are pushed together. Then, with a quick start forward the first car is set in motion. This technique is employed to overcome the static friction of each wheel (as well as the inertia of each car). It would be impossible for the engine to start all of the cars at the same instant, for static friction, which is the resistance of being set in motion, would be greater than the force exerted by the engine. Once the cars are in motion, however, static friction is greatly reduced and a smaller force is required to keep the train in motion than was required to start it.

Sliding Friction

Sliding friction is the resistance to motion offered by an object sliding over a surface. It pertains to friction produced after the object has been set in motion, and is always less than starting friction. The amount of sliding resistance is dependent on the nature of the surface of the object, the surface over which it slides, and the normal force between the object and the surface. This resistive force may be computed by using the following formula.

$$F = mN$$

AIRCRAFT
TECHNICAL
BOOK COMPANY

In the formula above, "F" is the resistive force due to friction expressed in pounds; "N" is the force exerted on or by the object perpendicular (normal) to the surface over which it slides; and "m" (mu) is the coefficient of sliding friction. On a horizontal surface, N is equal to the weight of the object in pounds. The area of the sliding object exposed to the sliding surface has no effect on the results. A block of equally textured wood, for example, will not slide on any one side easier than another. Therefore, area does not enter into the equation above.

Rolling Friction
Resistance to motion is greatly reduced if an object is mounted on wheels or rollers. The force of friction for objects mounted on wheels or rollers is called rolling friction. This force may be computed by the same equation used in computing sliding friction, but the values of "m" will be much smaller. For example, the value of "m" for rubber tires on concrete or macadam is about 0.02. The value of "m" for roller bearings is very small, usually ranging from 0.001 to 0.003 and is often disregarded.

Example: An aircraft with a gross weight of 79 600 lbs is towed over a concrete ramp. What force must be exerted by the towing vehicle to keep the airplane rolling after once set in motion?

$$F = mN$$
$$= 0.02 \text{ mu} \times 79\ 600 \text{ lb}$$
$$= 1\ 592 \text{ lb}$$

Coefficient Of Friction
Coefficient of friction is a value that shows the relationship between the force of friction between two objects and the normal reaction between the objects that are involved. It is a value that is sometimes used in physics to find an object's normal force or frictional force when other methods are unavailable.

The coefficient can be two different things. It is either the coefficient of static friction or the coefficient of kinetic friction. The coefficient of static friction is the friction force between two objects when neither of the objects is moving. The coefficient of kinetic friction is the force between two objects when one object is moving, or if both objects are moving against one another.

The coefficient of friction depends on the objects that are causing friction. The value is usually between 0 and 1 but can be greater than 1. A value of 0 means there is no friction at all between the objects. This is only theoretically possible as all objects in the real world will have some friction when they touch each other. A value of 1 means the frictional force is equal to the normal force. A value more than one just means that friction is stronger than the normal force. An material such as rubber for example, can have a coefficient greater than one. The coefficient of friction can also be changed by the mass and speed of the moving object.

2.2.4 - FLUID DYNAMICS

DENSITY
The density of a substance is its weight per unit volume. The unit volume selected for use in the Imperial system of measurement is 1 cubic foot (ft³). In the metric system, it is 1 cubic centimeter (cm³). Therefore, density is expressed in pounds per cubic foot (lb/ft³) or grams per cubic centimeter (g/cm³).

To find the density of a substance, its weight and volume must be known. Its weight is then divided by its volume to find the weight per unit volume. For example, the liquid which fills a certain container weighs 1 497.6 lb. The container is 4 ft long, 3 ft wide, and 2 ft deep. Its volume is 24 ft³ (4 ft × 3 ft × 2 ft). If 24 ft³ of liquid

weighs 1 497.6 lb, then 1 ft³ weighs 1 497.6 ÷ 24, or 62.4 lb. Therefore, the density of the liquid is 62.4 lb/ft³. This is the density of water at 4 ˚C (Celsius) and is usually used as the standard for comparing densities of other substances. In the metric system, the density of water is 1 g/cm³. The standard temperature of 4 ˚C is used when measuring the density of liquids and solids. Changes in temperature will not change the weight of a substance, but will change the volume of the substance by expansion or contraction, thus changing its weight per unit volume.

The procedure for finding density applies to all substances; however, it is necessary to consider the pressure when finding the density of gases. Pressure is more critical when measuring the density of gases than it is for other substances. The density of a gas increases in direct proportion to the pressure exerted on it. Standard conditions for the measurement of the densities of gases have been established at 0 °C for temperature and a pressure of 760 mm of mercury (Hg). (This is the average pressure of the atmosphere at sea level.) Density is computed based on these conditions for all gases.

SPECIFIC GRAVITY

It is often necessary to compare the density of one substance with that of another. For this purpose, a standard is needed. Water is the standard that physicists have chosen to use when comparing the densities of all liquids and solids. For gases, air is most commonly used. However, hydrogen is sometimes used as a standard for gases. In physics, the word "specific" implies a ratio. Thus, specific gravity is calculated by comparing the weight of a definite volume of the given substance with the weight of an equal volume of water. The terms "specific weight" or "specific density" are sometimes used to express this ratio.

The following formulas are used to find the specific gravity of liquids and solids.

$$\text{Specific Gravity} = \frac{\text{Weight of the substance}}{\text{Weight of an equal volume of water}}$$

or,

$$\text{Specific Gravity} = \frac{\text{Density of the substance}}{\text{Density of water}}$$

The same formulas are used to find the density of gases by substituting air or hydrogen for water.

Specific gravity is not expressed in units, but as pure numbers. For example, if a certain hydraulic fluid has a specific gravity of 0.8, 1 ft³ of the liquid weighs 0.8 times as much as 1 ft³ of water: 62.4 times 0.8, or 49.92 lb.

Specific gravity and density are independent of the size of the sample under consideration and depend only upon the substance of which it is made. See *Figure 2-35* for typical values of specific gravity for various substances.

Liquid	Specific Gravity	Solid	Specific Gravity	Gas	Specific Gravity
Gasoline	0.72	Ice	0.917	Hydrogen	0.069 5
Jet Fuel Jp-4	0.785	Aluminum	2.7	Helium	0.138
Ethyl Alcohol	0.789	Titanium	4.4	Acetylene	0.898
Jet Fuel Jp-5	0.82	Zinc	7.1	Nitrogen	0.967
Kerosene	0.82	Iron	7.9	Air	1.000
Lube Oil	0.89	Brass	8.4	Oxygen	1.105
Synthetic Oil	0.928	Copper	8.9	Carbon Dioxide	1.528
Water	1.000	Lead	11.4		
Sulfuric Acid	1.84	Gold	19.3		
Mercury	13.6	Platinum	21.5		

Figure 2-35. Specific gravity of various substances.

A device called a hydrometer is used for measuring specific gravity of liquids. This device consists of a tubular glass float contained in a larger glass tube. (*Figure 2-36*) The larger glass tube provides the container for the liquid. A rubber suction bulb draws the liquid up into the container. There must be enough liquid to raise the float and prevent it from touching the bottom. The float is weighted and has a vertically graduated scale. To determine specific gravity, the scale is read at the surface of the liquid in which the float is immersed. An indication of 1 000 is read when the float is immersed in pure water. When immersed in a liquid of greater density, the float rises, indicating a greater specific gravity. For liquids of lesser density the float sinks, indicating a lower specific gravity.

An example of the use of the hydrometer is to determine the specific gravity of the electrolyte (battery liquid) in an aircraft battery. When a battery is discharged, the calibrated float immersed in the electrolyte will indicate approximately 1 150. The indication of a charged battery is between 1 275 and 1 310. The values 1 150; 1 275; and 1 310 actually represent 1.150; 1.275; and 1.310. The electrolyte in a discharged battery is 1.15 times denser than water, and in a charged battery 1.275 to 1.31 times denser than water.
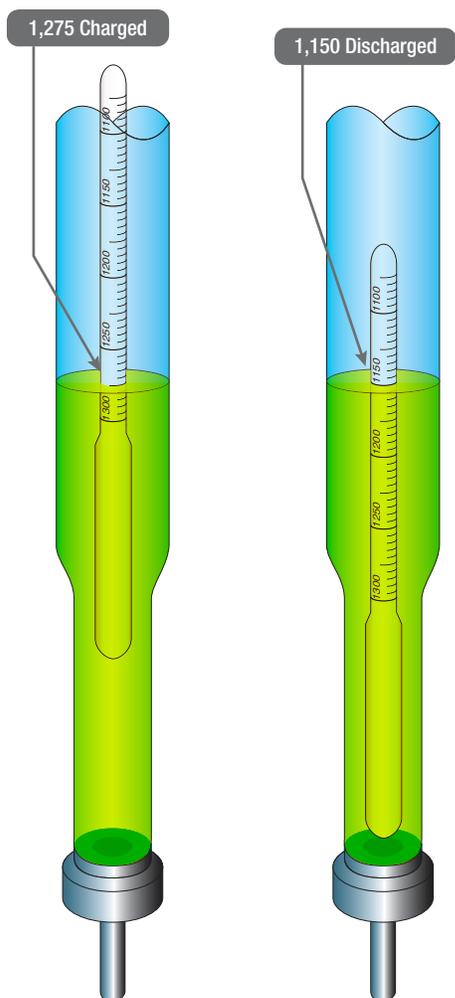
Figure 2-36. Hydrometer for checking battery specific gravity.

VISCOSITY

One of the most important properties of any fluid is its viscosity. Viscosity is internal resistance to flow. A liquid such as gasoline that has a low viscosity flows easily, while a liquid such as tar that has a high viscosity flows slowly. All fluids have viscosity. While easier to see in a liquid, gases, such as air, also have viscosity. In aerodynamics, as air flows over the surfaces of an aircraft, the viscosity of the air affects the nature of the flow.

Viscosity increases as temperature decreases. A satisfactory liquid for a given hydraulic system, for example, must have enough body to give a good seal at pumps, valves, and pistons, but it must not be so thick that it offers resistance to flow, leading to power loss and higher operating temperatures. These factors add to the load and to excessive wear of parts. A fluid with viscosity that is too low also leads to rapid wear of moving parts or of parts that have heavy loads.

Maintaining a functional viscosity throughout the operating temperature range is also an issue in lubricating systems. A viscosity index is a number that indicates the effect of temperature changes on the viscosity of lubricating oil. A low viscosity index signifies a relatively large change of viscosity during temperature variations. A high viscosity index indicates the fluid experiences small changes in viscosity as temperature varies.

The instruments used to measure the viscosity of a liquid are known as viscometers or viscosimeters. Several types of viscosimeters are in use today. The Saybolt viscometer measures the time required, in seconds, for 60 milliliters of the tested fluid at 100 ˚F to pass through a standard orifice. The time measured is used to express the fluid's viscosity, in Saybolt universal seconds or Saybolt furol seconds. (**Figure 2-37**)

FLUID RESISTANCE

A fluid, by definition, is any substance that is able to flow if it is not in some way confined or restricted. Liquids and gases are both classified as fluids, and often act in a very similar way. One significant difference comes into play when a force is applied to these fluids. In this case, liquids tend to be incompressible and gases are highly compressible. Many of the principles that aviation is based on, such as the theory of lift on a wing and the force generated by a hydraulic system, can be explained and quantified by using the laws of fluid mechanics.
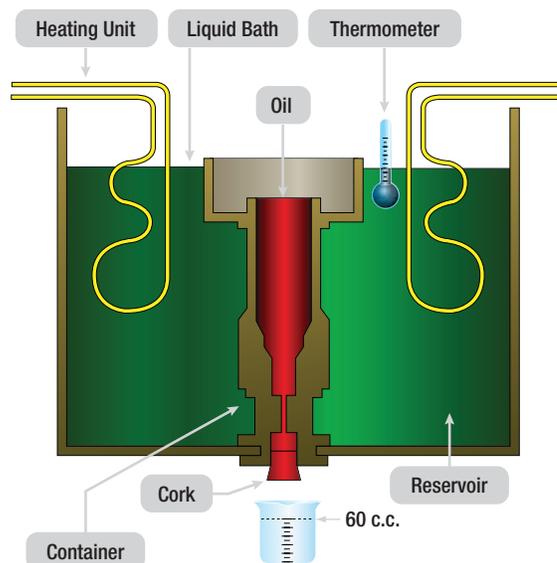
Figure 2-37. Saybolt viscosimeter.

PASCAL'S LAW

The foundations of modern hydraulics and pneumatics were established in 1653 when Pascal discovered that pressure set up in a fluid acts equally in all directions. This pressure acts at right angles to containing surfaces.

When the pressure in the fluid is caused solely by the fluid's height, the pressure against the walls of the container is equal at any given level, but it is not equal if the pressure at the bottom is compared to the pressure half way down. The concept of the pressure set up in a fluid, and how it relates to the force acting on the fluid and the surface area through which it acts, is Pascal's law.

In **Figure 2-5**, if a piston is placed at the top of the cylinder and an external force pushes down on the piston, additional pressure will be created in the liquid. If the additional pressure is 100 psi, this 100 psi will act equally and undiminished from the top of the cylinder all the way to the bottom. The gauge at the bottom will now read 108.34 psi, and if a gauge were positioned half way down the cylinder, it would read 104.17 psi (100 plus half of 8.34). Pascal's law, when dealing with the variables of force, pressure, and area, is dealt with by way of the following formula.

$$\text{Force} = \text{Pressure} \times \text{Area}$$

In this formula, the force is in units of pounds, the pressure is in pounds per square inch (psi), and the area is in square inches. By transposing the original formula, we have two additional formulas, as follows:

$$\text{Pressure} = \text{Force} \div \text{Area}$$
$$\text{and}$$
$$\text{Area} = \text{Force} \div \text{Pressure}$$

An easy and convenient way to remember the formulas for Pascal's law, and the relationship between the variables, is with the triangle shown in **Figure 2-38**. If the variable we want to solve for is covered up, the position of the remaining two variables shows the proper math relationship. For example, if the "A" (area) is covered up, what remains is the "F" on the top and the "P" on the bottom, meaning force divided by pressure.

The simple hydraulic system in **Figure 2-39** has a 5-lb force acting on a piston with a ½in² surface area. Based on Pascal's law, the pressure in the system would be
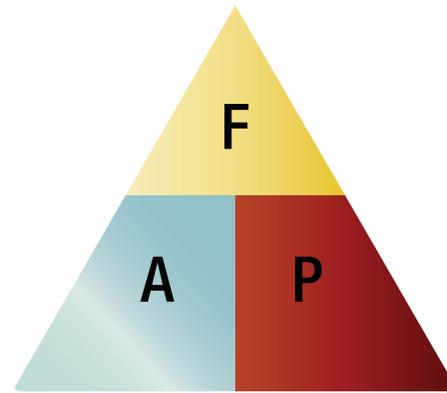
Figure 2-38. Force, area, pressure relationship.

equal to the force applied divided by the area of the piston, or 10 psi. As shown in **Figure 2-39**, the pressure of 10 psi is present everywhere in the fluid.

The hydraulic system in **Figure 2-40** is a little more complex than the one in **Figure 2-39**. In **Figure 2-40**, the input force of 5 lb is acting on a ½ in² piston, creating a pressure of 10 psi. The input cylinder and piston is connected to a second cylinder, which contains a 5 in² piston. The pressure of 10 psi created by the input piston pushes on the piston in the second cylinder, creating an output force of 50 pounds.

More often than not, the purpose of a hydraulic system is to generate a large output force, with the input force being much less. In **Figure 2-40**, the input force is 5 lb and the output force is 50 lbs, or 10 times greater. The relationship between the output force and the input force, as discussed earlier in this chapter, is known as mechanical advantage.

The mechanical advantage in **Figure 2-40** would be 50 divided by 5, or 10. The following formulas can be used to calculate mechanical advantage.

$$\text{Mechanical Advantage} = \text{Force Out} \div \text{Force In}$$
$$\text{Or}$$
$$\text{Mechanical Advantage} = \text{Distance Out} \div \text{Distance In}$$

Earlier in this chapter when simple machines, such as levers and gears were discussed, it was identified that no machine allows us to gain work. The same statement holds true for a hydraulic system, that we get no more work out of a hydraulic system than we put in. Since work is equal to force times distance, if we gain force with a hydraulic system, we must lose distance. We only get the same work out, if the system is 100 percent efficient.

$$\text{Pressure} = \text{Force} \div \text{Area}$$
$$\text{Pressure} = 5 \div \tfrac{1}{2}$$
$$\text{Pressure} = 10 \text{ psi}$$

Figure 2-39. Pressure created in a hydraulic system.

$$\text{Force} = \text{Pressure} \times \text{Area}$$
$$\text{Force} = 10 \text{ psi} \times 5 \text{ in}^2$$
$$\text{Force} = 50 \text{ lb}$$

Figure 2-40. Output force created in a hydraulic system.

In order to think about the distance that the output piston will move in response to the movement of the input piston, the volume of fluid displaced must be considered. In the study of geometry, one learns that the volume of a cylinder is equal to the cylinder's surface area multiplied by its height. So when a piston of 2 in² moves down in a cylinder a distance of 10 inches, it displaces a volume of fluid equal to 20 in³ (2 in² × 10 in). The 20 in³ displaced by the first piston is what moves over to the second cylinder and causes its piston to move.

In a simple two-piston hydraulic system, the relationship between the piston area and the distance moved is shown by the following formula.

Input Piston Area (Distance Moved) = Output Piston Area (Distance Moved)

In essence, this formula shows that the volume in is equal to the volume out. This concept is shown in *Figure 2-41*, where a small input piston moves a distance of 20 inches, and the larger output piston only moves a distance of 1 inch.

Example: A two-piston hydraulic system, like that shown in *Figure 2-41*, has an input piston with an area of ¼ in² and an output piston with an area of 15 in².

$$\text{Piston Area (distance)} = \text{Piston Area (distance)}$$
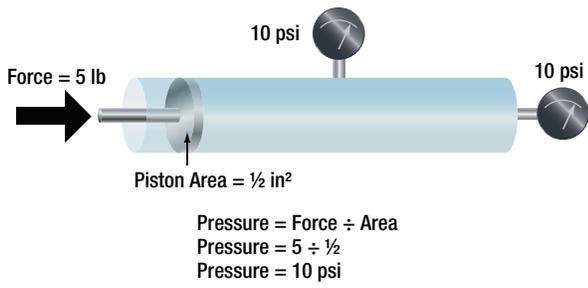$$\tfrac{1}{4} \text{ in}^2 (20 \text{ in}) = 5 \text{ in (distance)}$$
$$5 \div 5 = \text{Distance}$$
$$\text{Distance} = 1 \text{ in}$$

Figure 2-41. Piston movement in a hydraulic system.

An input force of 50 lbs is applied, and the input piston moves 30 inches. What is the pressure in the system, how much force is generated by the output piston, how far would the output piston move, and what is the mechanical advantage?

$$
\begin{aligned}
\text{Pressure} &= \text{Force} \div \text{Area} \\
&= 50 \div \tfrac{1}{4} = 200 \text{ psi} \\
\text{Force} &= \text{Pressure} \times \text{Area} \\
&= 200 \times 15 \\
&= 3\,000 \text{ lb} \\
\text{Mechanical Advantage} &= \text{Force Out} \div \text{Force In} \\
&= 3\,000 \div 50 \\
&= 60
\end{aligned}
$$

Input Piston Area
$$
\begin{aligned}
\text{(Distance Moved)} &= \text{Output Piston Area} \\
&\quad \text{(Distance Moved)} \\
\tfrac{1}{4} (30) &= 15 \text{ (Distance Moved)} \\
\tfrac{1}{4} (30) \div 15 &= \text{Distance Moved} \\
\text{Distance Moved} &= \tfrac{1}{2} \text{ in}
\end{aligned}
$$

Part of understanding Pascal's law and hydraulics involves utilizing formulas, and recognizing the relationship between the individual variables. Before the numbers are plugged into the formulas, it is often possible to analyze the variables in the system and come to a realization about what is happening.

For example, look at the variables in *Figure 2-41* and notice that the output piston is 20 times larger than the input piston (5 in² compared to ¼ in²). That comparison tells us that the output force will be 20 times greater than the input force, and also that the output piston will only move half as far. Without doing any formula based calculations, we can conclude that the hydraulic system in question has a mechanical advantage of 20.

STREAMLINING

When a fluid encounters a particular obstacle to flow around, be it the wing of an aircraft or a curve in a hydraulic system line, a gradual curved surface enables the possibility of smooth flow which is free from turbulence. Fluid particles may be able to speed up to negotiate the obstacle smoothly without tumbling. This smooth flow is essential for low pressure development on the upper surface of a wing. Known as streamlining, the gradual shaping of areas where fluids must flow reduces the compression of gases and temperature of liquids in areas where turbulent flow may otherwise result.

COMPRESSIBILITY

In fluid dynamics, compressibility is a measure of how much the volume of the fluid changes as a response of pressure changes. Generally gases are considered to be compressible, while liquids are incompressible.

The main difference between compressible and incompressible fluids is that a force applied to a compressible fluid changes its density whereas a force applied to an incompressible fluid does not change it to a meaningful degree. In normal temperature and pressure conditions, the volume or the density of a gas does not change. However, they can easily with even small changes in temperature or pressure.

At the molecular level, when a pressure is applied on a gas, it affects the gas in all directions, causing the molecules of the gas to collide with greater frequency. These collisions give more time for the gas molecules to interact and more attraction forces occur between molecules. These attraction forces reduce the motion of gas molecules.

BERNOULLI'S PRINCIPLE

Bernoulli's principle explains the action of a liquid flowing through the varying cross-sectional areas of tubes. In *Figure 2-42* a tube is shown in which the cross-sectional area gradually decreases to a minimum diameter in its center section. A tube constructed in this manner is called a "venturi," or "venturi tube." Where the cross-sectional area is decreasing, the passageway is referred to as a converging duct. As the passageway starts to spread out, it is referred to as a diverging duct.

As a liquid (fluid) flows through the venturi tube, the gauges at points "A," "B," and "C" are positioned to register the velocity and the static pressure of the liquid. The venturi in *Figure 2-42* is used to illustrate Bernoulli's principle, which states that: The static pressure of a fluid (liquid or gas) decreases at points where the velocity of the fluid increases, provided no energy is added to nor taken away from the fluid. The velocity of the air is kinetic energy and the static pressure of the air is potential energy.

In the wide section of the venturi (*points A and C of Figure 2-42*), the liquid moves at low velocity, producing a high static pressure, as indicated by the pressure gauge. As the tube narrows in the center, it must contain the same volume of fluid as the two end areas. In this narrow section, the liquid moves at a higher velocity, producing a lower pressure than that at points A and C, as indicated by the velocity gauge reading high and the pressure gauge reading low.

A good application of Bernoulli's principle is in a float-type carburetor. As the air flows through the carburetor on its way to the engine, it goes through a venturi, where the static pressure is reduced. The fuel in the carburetor, which is under a higher pressure, flows into the lower pressure venturi area and mixes with the air.

Bernoulli's principle is extremely important in understanding how some of the systems used in aviation work, including how the wing of an airplane generates lift or why the inlet duct of a turbine engine on a subsonic airplane is diverging in shape. The wing on a slow moving airplane has a curved top surface and
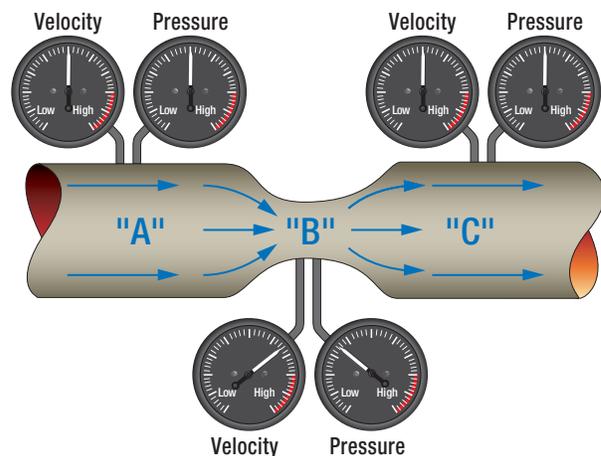
Figure 2-42. Bernoulli's principle and a venturi.

a relatively flat bottom surface. The curved top surface acts like half of the converging shaped middle of a venturi. As the air flows over the top of the wing, the air speeds up, and its static pressure decreases. The static pressure on the bottom of the wing is now greater than the pressure on the top, and this pressure difference creates the lift on the wing. Bernoulli's principle and the concept of lift on a wing is covered in greater depth in *Module 08 – Basic Aerodynamics*.

Key to Bernoulli's principle is that the total pressure of the airflow remains the same while static pressure varies due to negotiation of the curvature of a venturi or wing. As the static pressure of the fluid decreases to move over the curved surface, dynamic pressure increases. Dynamic pressure is associated with the kinetic energy in the airflow.

Expressed as an equation:

Total Pressure = Static Pressure + Dynamic Pressure

Question: 2-1
What is force?

Question: 2-5
F = MA is the formula derived from Newton's second law that calculates _____.

Question: 2-2
Name the five stresses that may act on an object.

Question: 2-6
When a pendulum swings, what remains the same as the length of the swing arch changes?

Question: 2-3
Force has magnitude and _____.

Question: 2-7
Any device with which work may be accomplished is called a _____.

Question: 2-4
What causes atmospheric pressure?

Question: 2-8
What type of gear has a spiral threaded rod engaged with a spur gear?

AIRCRAFT
TECHNICAL
BOOK COMPANY

ANSWERS

Answer: 2-1
The influence that tends to change the motion of an object or produce stress in a stationary object.

Answer: 2-2
Tension.
Compression.
Torsion.
Shear.
Bending.

Answer: 2-3
direction.

Answer: 2-4
The weight of the air above the point of measurement.

Answer: 2-5
thrust.

Answer: 2-6
The period.

Answer: 2-7
machine.

Answer: 2-8
Worm gear.

SUB-MODULE 03

Sub-Module 03
THERMODYNAMICS
Knowledge Requirements

2.3 – Thermodynamics

		B1	B2
(a)	Temperature: thermometers and temperature scales: Celsius, Fahrenheit and Kelvin; Heat definition;	2	2
(b)	Heat capacity, specific heat; Heat transfer: convection, radiation and conduction; Volumetric expansion; First and second law of thermodynamics; Gases: ideal gases laws; specific heat at constant volume and constant pressure, work done by expanding gas; Isothermal, adiabatic expansion and compression, engine cycles, constant volume and constant pressure, refrigerators and heat pumps; Latent heats of fusion and evaporation, thermal energy, heat of combustion.	2	2

AIRCRAFT
TECHNICAL
BOOK COMPANY

2.3 - THERMODYNAMICS

Thermodynamics is the branch of physical science that deals with the relations between heat and other forms of energy.

TEMPERATURE

Temperature is a dominant factor affecting the physical properties of fluids. It is of particular concern when calculating changes in the state of gases. The four temperature scales used extensively are the Celsius, the Fahrenheit, the absolute or Kelvin, and the Rankine scales. The Celsius scale is constructed by using the freezing and boiling points of water, under standard conditions, as fixed points of zero and 100, respectively, with 100 equal divisions between. The Fahrenheit scale uses 32° as the freezing point of water and 212° as the boiling point, and has 180 equal divisions between. The absolute or Kelvin scale is constructed with its zero point established as minus 273 °C, meaning 273° below the freezing point of water. The relationships of the other fixed points of the scales are shown in *Figure 3-1*.

When working with temperatures, always make sure which system of measurement is being used and know how to convert from one to another. The conversion formulas are as follows:

Degrees Fahrenheit = (1.8 × Degrees Celsius) + 32
Degrees Celsius = (Degrees Fahrenheit – 32) × 5/9
Degrees Kelvin = Degrees Celsius + 273
Degrees Rankine = Degrees Fahrenheit + 460

For purposes of calculations, the Rankine scale is commonly used to convert Fahrenheit to absolute. For Fahrenheit readings above zero, 460° is added. Thus, 72 °F equals 460° plus 72°, or 532° absolute. If the Fahrenheit reading is below zero, it is subtracted from 460°. Thus –40 °F equals 460° minus 40°, or 420° absolute. It should be stressed that the Rankine scale does not indicate absolute temperature readings in accordance with the Kelvin scale, but these conversions may be used for the calculations of changes in the state of gases.

The Kelvin and Celsius scales are SI scales used extensively in scientific work. Technical manuals may use these scales in giving directions and operating instructions. The Fahrenheit and Celsius scales are used in most areas of this module.

THERMAL EXPANSION/CONTRACTION

Thermal expansion takes place in solids, liquids, and gases when they are heated. With few exceptions, solids will expand when heated and contract when cooled. Because the molecules of solids are much closer together and are more strongly attracted to each other, the expansion of solids when heated is very slight in comparison to the expansion in liquids and gases. The expansion of fluids is discussed in the study of Boyle's law. Thermal expansion in solids must be explained in some detail because of its close relationship to aircraft metals and materials.

Because some substances expand more than others, it is necessary to measure experimentally the exact rate of expansion of each one. The amount that a unit length of any substance expands for a one degree rise in temperature is known as the coefficient of linear expansion for that substance. The coefficient of linear expansion for various materials is shown in *Figure 3-2*.

To estimate the expansion of any object, such as a steel rail, it is necessary to know three things about it: its length, the rise in temperature to which it is subjected, and its coefficient of expansion. This relationship is expressed by the equation:

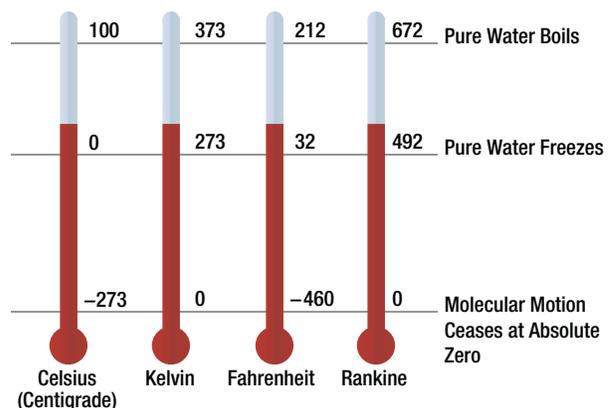Expansion = (coefficient) × (length) × (rise in temp.)

Figure 3-1. Comparison of temperature scales.

Substance	Coefficient of Expansion Per Degree Celsius
Aluminum	25×10^{-6}
Brass or Bronze	19×10^{-6}
Brick	9×10^{-6}
Copper	17×10^{-6}
Glass (Plate)	9×10^{-6}
Glass (Pyrex)	3×10^{-6}
Ice	51×10^{-6}
Iron or Steel	11×10^{-6}
Lead	29×10^{-6}
Quartz	0.4×10^{-6}
Silver	19×10^{-6}

Figure 3-2. Coefficient of expansion for various materials.

If a steel rod measures exactly 9 ft at 21 °C, what is its length at 55 °C? The coefficient of expansion for steel is $11 \times 10{-6}$.

$$\text{Expansion} = (11 \times 10 - 6) \times (9 \text{ feet}) \times 34°$$
$$\text{Expansion} = 0.003\ 366 \text{ feet}$$

This amount, when added to the original length of the rod, makes the rod 9.003 366 ft long. Its length has only increased by 3/1000 of an inch.

The increase in the length of the rod is relatively small, but if the rod were placed where it could not expand freely, there would be a tremendous force exerted due to thermal expansion. Thus, thermal expansion must be taken into consideration when designing airframes, powerplants, or related equipment.

HEAT ENERGY UNITS

The SI unit used to express quantities of heat energy is the joule. Two different non-SI units are used to express quantities of heat energy. They are the calorie and the BTU. One calorie is equal to the amount of heat required to change the temperature of 1 gram of water 1 degree Celsius.

This term "calorie" (spelled with a lower case c) is 1/1000 of the Calorie (spelled with a capital C) used in the measurement of the heat energy in foods. One BTU is defined as the amount of heat required to change the temperature of 1 lb of water 1 degree Fahrenheit (1 °F). The calorie and the gram are seldom used in discussing

aviation maintenance. The BTU, however, is commonly referred to in discussions of engine thermal efficiencies and the heat content of aviation fuel.

A device known as the calorimeter is used to measure quantities of heat energy. For example, it may be used to determine the quantity of heat energy available in 1 pound of aviation gasoline. A given weight of the fuel is burned in the calorimeter, and the heat energy is absorbed by a large quantity of water. From the weight of the water and the increase in its temperature, it is possible to compute the heat yield of the fuel. A definite relationship exists between heat and mechanical energy. This relationship has been established and verified by many experiments which show that:

One BTU of heat energy = 778 ft-lb of work

One pound of aviation gasoline contains 18 900 BTU of heat energy. Since each BTU is capable of 778 ft-lb of work, 1 lb of aviation gasoline is capable of 14 704 200 ft-lb of work.

THERMOMETERS

A thermometer is a temperature measuring instrument. The temperature of numerous items must be known for an aircraft to be operated properly. Engine oil, carburetor mixture, inlet air, free air, engine cylinder heads, heater ducts, and exhaust gas temperature of turbine engines are all items requiring temperature monitoring. Many other temperatures must also be known. Different types of thermometers are used to collect and present temperature information.

NON-ELECTRIC TEMPERATURE INDICATORS

The physical characteristics of most materials change when exposed to changes in temperature. The changes are consistent, such as the expansion or contraction of solids, liquids, and gases. The coefficient of expansion of different materials varies and it is unique to each material. Most everyone is familiar with the liquid mercury thermometer. As the temperature of the mercury increases, it expands up a narrow passage that has a graduated scale upon it to read the temperature associated with that expansion. The mercury thermometer has no application in aviation.

A bimetallic thermometer is very useful in aviation. The temperature sensing element of a bimetallic thermometer is made of two dissimilar metals strips bonded together. Each metal expands and contracts at a different rate when temperature changes. One end of the bimetallic strip is fixed, the other end is coiled. A pointer is attached to the coiled end which is set in the instrument housing. When the bimetallic strip is heated, the two metals expand. Since their expansion rates differ and they are attached to each other, the effect is that the coiled end tries to uncoil as the one metal expands faster than the other. This moves the pointer across the dial face of the instrument. When the temperature drops, the metals contract at different rates, which tends to tighten the coil and move the pointer in the opposite direction.

Direct reading bimetallic temperature gauges are often used in light aircraft to measure free air temperature or outside air temperature (OAT). In this application, a collecting probe protrudes through the windshield of the aircraft to be exposed to the atmospheric air. The coiled end of the bimetallic strip in the instrument head is just inside the windshield where it can be read by the pilot. (*Figures 3-3 and 3-4*)

A bourdon tube is also used as a direct reading non-electric temperature gauge in simple, light aircraft. By calibrating the dial face of a bourdon tube gauge with a temperature scale, it can indicate temperature. The basis for operation is the consistent expansion of the vapor produced by a volatile liquid in an enclosed area. This vapor pressure changes directly with temperature. By filling a sensing bulb with such a volatile liquid and connecting it to a bourdon tube, the tube causes an indication of the rising and falling vapor pressure due to temperature change. Calibration of the dial face in degrees Fahrenheit or Celsius, rather than psi, provides a temperature reading. In this type of gauge, the sensing bulb is placed in the area needing to have temperature measured. A long capillary tube connects the bulb to the bourdon tube in the instrument housing. The narrow diameter of the capillary tube ensures that the volatile liquid is lightweight and stays primarily in the sensor bulb. Oil temperature is sometimes measured this way.

ELECTRICAL TEMPERATURE INDICATION

The use of electricity in measuring temperature is very common in aviation. The following measuring and indication systems can be found on many types of aircraft. Certain temperature ranges are more suitably measured by one or another type of system.

Bimetallic Temperature Gauge

Bimetallic coil of bonded metals with dissimilar coefficients of expansion.

Figure 3-3. A bimetallic temperature gauge works because of the dissimilar coefficients of expansion of two metals bonded together. When bent into a coil, cooling or heating causes the dissimilar metal coil to tighten, or unwind, moving the pointer across the temperature scale on the instrument dial face.

Figure 3-4. A bimetallic outside air temperature gauge and its installation on a light aircraft.

Electrical Resistance Thermometers

Principle parts of the electrical resistance thermometer are the indicating instrument, the temperature sensitive element (or bulb), and the connecting wires and plug connectors. Electrical resistance thermometers are used widely in many types of aircraft to measure carburetor air, oil, free air temperatures, and more. They are used to measure low and medium temperatures in the –70 °C to 150 °C range.

For most metals, electrical resistance changes as the temperature of the metal changes. This is the principle upon which a resistance thermometer operates. Typically, the electrical resistance of a metal increases as the temperature rises. Various alloys have a high temperature-resistance coefficient, meaning their resistance varies significantly with temperature. This can make them suitable for use in temperature sensing devices. The metal resistor is subjected to the fluid or area in which temperature needs to be measured. It is connected by wires to a resistance measuring device inside the cockpit indicator. The instrument dial is calibrated in degrees Fahrenheit or Celsius as desired rather than in ohms. As the temperature to be measured changes, the resistance of the metal changes and the resistance measuring indicator shows to what extent.

A typical electrical resistance thermometer looks like any other temperature gauge. Indicators are available in dual form for use in multiengine aircraft. Most indicators are self-compensating for changes in cockpit temperature. The heat-sensitive resistor is manufactured so that it has a definite resistance for each temperature value within its working range. The temperature-sensitive resistor element is a length or winding made of a nickel/manganese wire or other suitable alloy in an insulating material. The resistor is protected by a closed-end metal tube attached to a threaded plug with a hexagonal head. (*Figure 3-5*) The two ends of the winding are brazed, or welded, to an electrical receptacle designed to receive the prongs of the connector plug.

The indicator contains a resistance-measuring instrument. Sometimes it uses a modified form of the Wheatstonebridge circuit. The Wheatstone-bridge meter operates on the principle of balancing one unknown resistor against other known resistances. A simplified form of a Wheatstonebridge circuit is shown in *Figure 3-6*.

Figure 3-5. An electric resistance thermometer sensing bulb.

Three equal values of resistance (*Figure 3-6A, B, and C*) are connected into a diamond shaped bridge circuit. A resistor with an unknown value (*Figure 3-6D*) is also part of the circuit. The unknown resistance represents the resistance of the temperature bulb of the electrical resistance thermometer system. A galvanometer is attached across the circuit at points X and Y.

When the temperature causes the resistance of the bulb to equal that of the other resistances, no potential difference exists between points X and Y in the circuit. Therefore, no current flows in the galvanometer leg of the circuit. If the temperature of the bulb changes, its resistance also changes, and the bridge becomes unbalanced, causing current to f low through the galvanometer in one direction or the other. The galvanometer pointer is actually the temperature gauge pointer. As it moves against the dial face calibrated in degrees, it indicates temperature. Many indicators are provided with a zero adjustment screw on the face of the instrument. This adjusts the zeroing spring tension of
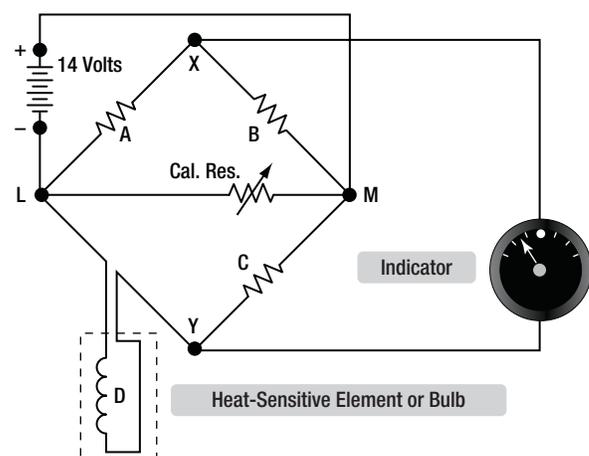

Figure 3-6. Internal structure of an electric resistance thermometer indicator features a bridge circuit, galvanometer, and variable resistor, which is outside the indicator in the form of the temperature sensor.

the pointer when the bridge is at the balance point (the position at which the bridge circuit is balanced and no current flows through the meter).

Ratiometer Electrical Resistance Thermometers

Another way of indicating temperature when employing an electric resistance thermometer is by using a ratiometer. The Wheatstone-bridge indicator is subject to errors from line voltage fluctuation. The ratiometer is more stable and can deliver higher accuracy. As its name suggests, the ratiometer electrical resistance thermometer measures a ratio of current flows.

The resistance bulb sensing portion of the ratiometer electric resistance thermometer is essentially the same as described above. The circuit contains a variable resistance and a fixed resistance to provide the indication. It contains two branches for current flow. Each has a coil mounted on either side of the pointer assembly that is mounted within the magnetic field of a large permanent magnet. Varying current flow through the coils causes different magnetic fields to form, which react with the larger magnetic field of the permanent magnet. This interaction rotates the pointer against the dial face that is calibrated in degrees Fahrenheit or Celsius, giving a temperature indication. (**Figure 3-7**)

The magnetic pole ends of the permanent magnet are closer at the top than they are at the bottom. This causes the magnetic field lines of flux between the poles to be more concentrated at the top. As the two coils produce their magnetic fields, the stronger field interacts and pivots downward into the weaker, less concentrated
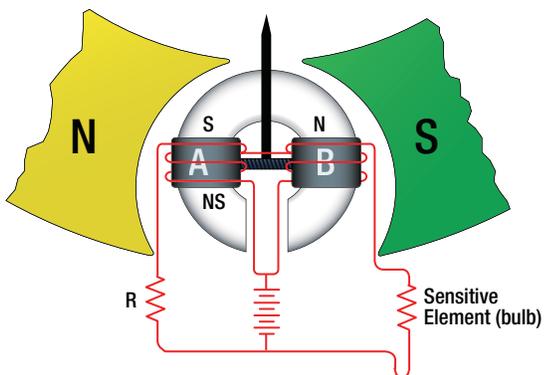

Figure 3-7. A ratiometer temperature measuring indicator has two coils. As the sensor bulb resistance varies with temperature, different amounts of current flow through the coils. This produces varying magnetic fields. These fields interact with the magnetic field of a large permanent magnet, resulting in an indication of temperature.

part of the permanent magnet field, while the weaker coil magnetic field shifts upward toward the more concentrated flux field of the large magnet. This provides a balancing effect that changes but stays in balance as the coil field strengths vary with temperature and the resultant current flowing through the coils.

For example, if the resistance of the temperature bulb is equal to the value of the fixed resistance (R), equal values of current flow through the coils. The torques, caused by the magnetic field each coil creates, are the same and cancel any movement in the larger magnetic field. The indicator pointer will be in the vertical position. If the bulb temperature increases, its resistance also increases. This causes the current flow through coil A circuit branch to increase. This creates a stronger magnetic field at coil A than at coil B. Consequently, the torque on coil A increases, and it is pulled downward into the weaker part of the large magnetic field. At the same time, less current flows through the sensor bulb resistor and coil B, causing coil B to form a weaker magnetic field that is pulled upward into the stronger f lux area of the permanent magnet's magnetic field. The pointer stops rotating when the fields reach a new balance point that is directly related to the resistance in the sensing bulb. The opposite of this action would take place if the temperature of the heat-sensitive bulb should decrease.

Ratiometer temperature measuring systems are used to measure engine oil, outside air, carburetor air, and other temperatures in many types of aircraft. They are especially in demand to measure temperature conditions where accuracy is important, or large variations of supply voltages are encountered.

Thermocouple Temperature Indicators

A thermocouple is a circuit or connection of two unlike metals. The metals are touching at two separate junctions. If one of the junctions is heated to a higher temperature than the other, an electromotive force is produced in the circuit. This voltage is directly proportional to the temperature. So, by measuring the amount of electromotive force, temperature can be determined. A voltmeter is placed across the colder of the two junctions of the thermocouple. It is calibrated in degrees Fahrenheit or Celsius, as needed. The hotter the high temperature junction (hot junction) becomes, the greater the electromotive force produced, and the higher the temperature indication on the meter. (**Figure 3-8**)
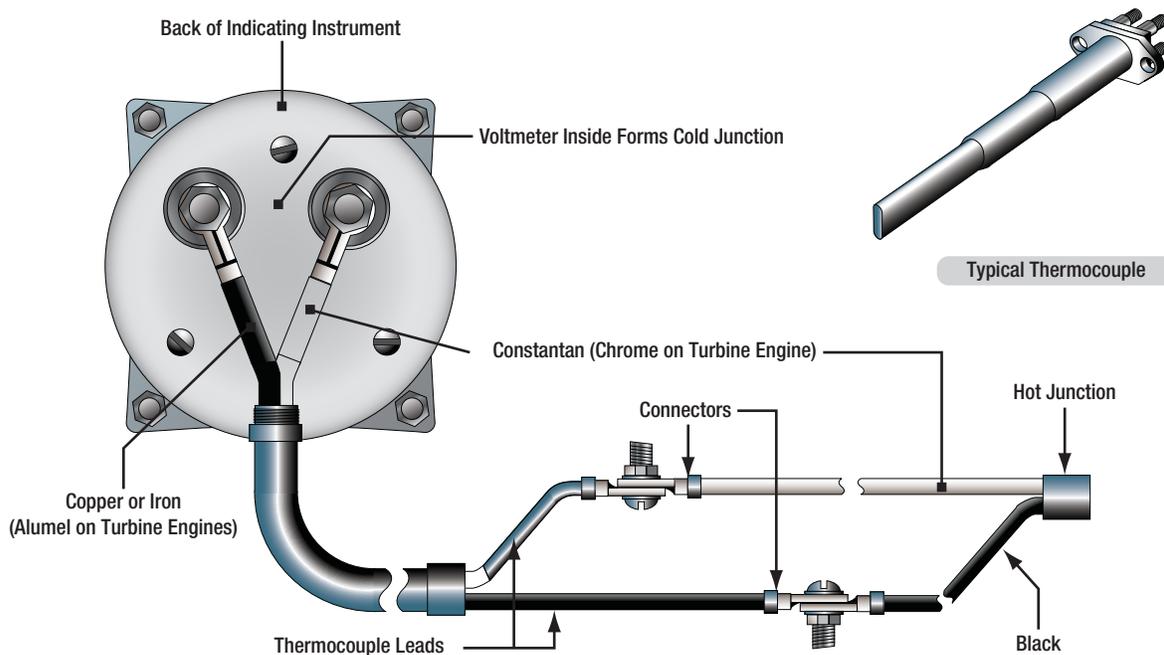
AIRCRAFT
TECHNICAL
BOOK COMPANY

Figure 3-8. Thermocouples combine two unlike metals that cause current flow when heated.

Thermocouples are used to measure high temperatures. Two common applications are the measurement of cylinder head temperature (CHT) in reciprocating engines and exhaust gas temperature (EGT) in turbine engines. Thermocouple leads are made from a variety of metals, depending on the maximum temperature to which they are exposed. Iron and constantan, or copper and constantan, are common for CHT measurement. Chromel and alumel are used for turbine EGT thermocouples.

The amount of voltage produced by the dissimilar metals when heated is measured in millivolts. Therefore, thermocouple leads are designed to provide a specific amount of resistance in the thermocouple circuit (usually very little). Their material, length, or cross-sectional size cannot be altered without compensation for the change in total resistance that would result. Each lead that makes a connection back to the voltmeter must be made of the same metal as the part of the thermocouple to which it is connected. For example, a copper wire is connected to the copper portion of the hot junction and a constantan wire is connected to the constantan part.

The hot junction of a thermocouple varies in shape depending on its application. Two common types are the gasket and the bayonet. In the gasket type, two rings of the dissimilar metals are pressed together to form a gasket that can be installed under a spark plug

or cylinder hold down nut. In the bayonet type, the metals come together inside a perforated protective sheath. Bayonet thermocouples fit into a hole or well in a cylinder head. On turbine engines, they are found mounted on the turbine inlet or outlet case and extend through the case into the gas stream. Note that for CHT indication, the cylinder chosen for the thermocouple installation is the one that runs the hottest under most operating conditions. The location of this cylinder varies with different engines. (*Figure 3-9*)

The cold junction of the thermocouple circuit is inside the instrument case. Since the electromotive force set up in the circuit varies with the difference in temperature between the hot and cold junctions, it is necessary to compensate the indicator mechanism for changes in cockpit temperature which affect the cold junction. This is accomplished by using a bimetallic spring connected to the indicator mechanism. This actually works the same as the bimetallic thermometer described previously. When the leads are disconnected from the indicator, the temperature of the cockpit area around the instrument panel can be read on the indicator dial. (*Figure 3-10*) Numeric LED indictors for CHT are also common in modern aircraft.
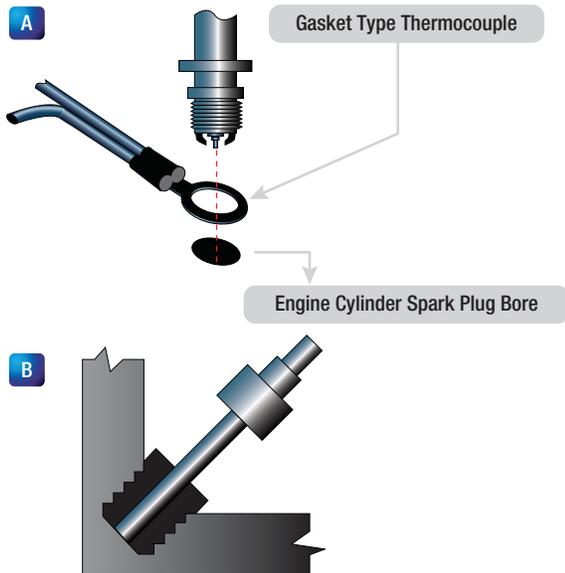
Figure 3-9. A cylinder head temperature thermocouple with a gasket type hot junction is made to be installed under the spark plug or a cylinder hold down nut of the hottest cylinder (A). A bayonet type thermocouple is installed in a bore in the cylinder wall (B).

HEAT DEFINITION

Heat is a form of energy. It is produced only by the conversion of one of the other forms of energy. Heat may also be defined as the total kinetic energy of the molecules of any substance. Some forms of energy which can be converted into heat energy are as follows:

- • Mechanical Energy. This includes all methods of producing increased motion of molecules such as friction, impact of bodies, or compression of gases.
- • Electrical Energy. Electrical energy is converted to heat energy when an electric current flows through any form of resistance such as an electric iron, electric light, or an electric blanket.
- • Chemical Energy. Most forms of chemical reaction convert stored potential energy into heat. Some examples are the explosive effects of gunpowder, the burning of oil or wood, and the combining of oxygen and grease.
- • Radiant Energy. Electromagnetic waves of certain frequencies produce heat when they are absorbed by the bodies they strike such as x-rays, light rays, and infrared rays.
- • Nuclear Energy. Energy stored in the nucleus of atoms is released during the process of nuclear fission in a nuclear reactor or atomic explosion.
- • The Sun. All heat energy can be directly or indirectly traced to the nuclear reactions occurring in the sun.

When a gas is compressed, work is done and the gas becomes warm or hot. Conversely, when a gas under high pressure is allowed to expand, the expanding gas becomes cool. In the first case, work was converted into energy in the form of heat; in the second case heat energy was expended. Since heat is given off or absorbed, there must be a relationship between heat energy and work. Also, when two surfaces are rubbed together, the friction develops heat. However, work was required to cause the heat, and by experimentation, it has been shown that the work required and the amount of heat produced by friction are proportional. Thus, heat can be regarded as a form of energy.

According to this theory of heat as a form of energy, the molecules, atoms, and electrons in all bodies are in a continual state of motion. In a hot body, these small particles possess relatively large amounts of kinetic energy, but in cooler bodies they have less. Because the small particles are given motion, and hence kinetic energy, work must be done to slide one body over the other. Mechanical energy apparently is transformed, and what we know as heat is really kinetic energy of the small molecular subdivisions of matter.

SPECIFIC HEAT

One important way in which substances differ is in the requirement of different quantities of heat to produce the same temperature change in a given mass of the substance. Each substance requires a quantity of heat, called its specific heat capacity, to increase the temperature of a unit of its mass 1 °C. The specific heat of a substance is the ratio of its specific heat capacity to the specific heat capacity of water. Specific heat is expressed as a number which, because it is a ratio, has no units and applies to both the Imperial and the SI/metric systems.

It is fortunate that water has a high specific heat capacity. The larger bodies of water on the earth keep the air and solid matter on or near the surface of the earth at a fairly constant temperature. A great quantity of heat is required to change the temperature of a large lake or river. Therefore, when the temperature falls below that of such bodies of water, they give off large quantities of heat. This process keeps the atmospheric temperature at the surface of the earth from changing rapidly. The specific heat values of some common materials are listed in *Figure 3-11*.

Figure 3-10. Typical thermocouple temperature indicators.

Material	Specific Heat
Lead	0.031
Mercury	0.033
Brass	0.094
Copper	0.095
Iron or Steel	0.113
Glass	0.195
Alcohol	0.547
Aluminum	0.712
Water	1.000

Figure 3-11. Specific heat value for various substances.

Specific heat of a substance is considered in a constant volume or a constant pressure process. The constant pressure process causes a greater amount of heat to be required to change the temperature of a substance since energy is used to do the work of expanding the volume so that pressure can remain the same. The technician will most often experience references to specific heat at constant volumes.

HEAT TRANSFER

There are three methods by which heat is transferred from one location to another or from one substance to another. These three methods are conduction, convection, and radiation.

CONDUCTION

Heat transfer always takes place by areas of high heat energy migrating to areas of low heat energy. Heat transfer by conduction requires that there be physical contact between an object that has a large amount of heat energy and one that has a smaller amount of heat energy.

Everyone knows from experience that the metal handle of a heated pan can burn the hand. A plastic or wood handle, however, remains relatively cool even though it is in direct contact with the pan. The metal transmits the heat more easily than the wood because it is a better conductor of heat. Different materials conduct heat at different rates. Some metals are much better conductors of heat than others. Aluminum and copper are used in pots and pans because they conduct heat very rapidly. Woods and plastics are used for handles because they conduct heat very slowly.

Figure 3-12 illustrates the different rates of conduction of various metals. Of those listed, silver is the best conductor and lead is the poorest. As previously mentioned, copper and aluminum are used in pots and pans because they are good conductors. It is interesting to note that silver, copper, and aluminum are also excellent conductors of electricity.

Liquids are poorer conductors of heat than metals. Notice that the ice in the test tube shown in *Figure 3-13* is not melting rapidly even though the water at the top is boiling. The water conducts heat so poorly that not enough heat reaches the ice to melt it.
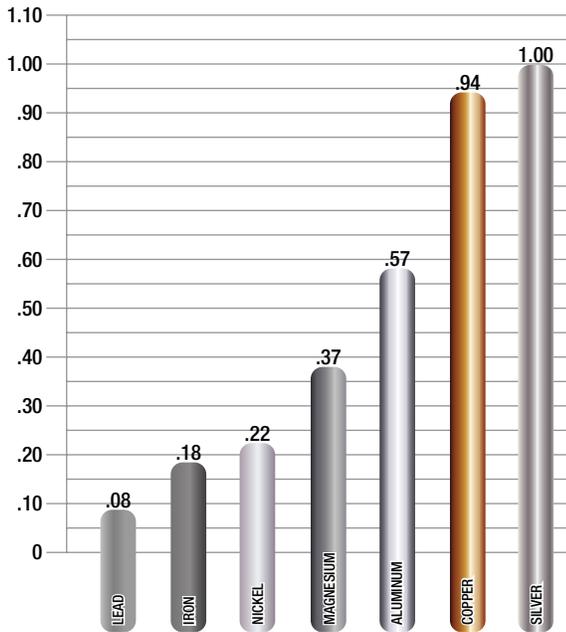
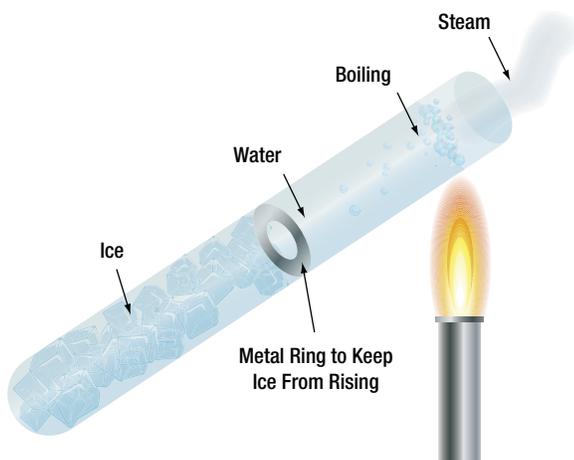Figure 3-12. Heat conductivity of various metals.

Figure 3-13. Water as a poor conductor.

Gases are even poorer conductors of heat than liquids. It is possible to stand quite close to a stove without being burned because air is such a poor conductor. Since conduction is a process whereby the increase in molecular energy is passed along by actual contact, gases, with molecules spaced further apart, are poor conductors.

At the point of application of the heat source, the molecules become violently agitated. These molecules strike adjacent molecules causing them to become agitated. This process continues until the heat energy is distributed evenly throughout the substance. Because molecules are farther apart in gases than in solids, the gases are much poorer conductors of heat.

Materials that are poor conductors are used to prevent the transfer of heat and are called heat insulators. A wooden handle on a pot or a soldering iron serves as a heat insulator. Certain materials, such as finely spun glass or asbestos, are particularly poor heat conductors. These materials are therefore used for many types of insulation.

CONVECTION

Convection is the process by which heat is transferred by movement of a heated fluid (gas or liquid). For example, an incandescent light bulb will, when heated, become increasingly hotter until the air surrounding it begins to move. The motion of the air is upward. This upward motion of the heated air carries the heat away from the hot light bulb by convection. Transfer of heat by convection may be hastened by using a ventilating fan to move the air surrounding a hot object. The rate of cooling of a hot electronics component, such as the CPU in a computer, can be increased if it is provided with copper fins that conduct heat away from the hot surface. The fins provide large surfaces against which cool air can be blown.

A convection process may take place in a liquid as well as in a gas. A good example of this is a pan of water sitting on the stove. The bottom of the pan becomes hot because it conducts heat from the surface it is in contact with. The water on the bottom of the pan also heats up because of conduction. As the heated water starts to rise and cooler water moves in to take its place, the convection process begins.

When the circulation of gas or liquid is not rapid enough to remove sufficient heat, fans or pumps are used to accelerate the motion of the cooling material. In some installations, pumps are used to circulate water or oil to help cool large equipment. In airborne installations, electric fans and blowers are used to aid convection.

An aircraft air-cooled piston engine is a good example of convection being used to transfer heat. The engine shown in *Figure 3-14* is a Continental IO-520, with six heavily finned air-cooled cylinders. This engine does not depend on natural convection for cooling, but rather forced air convection coming from the propeller on the engine. The heat generated inside the engine finds its way to the cylinder cooling fins by conduction, meaning transfer within the metal of the cylinder. Once the heat gets to the fins, forced air flowing around the cylinders carries the heat away.

Figure 3-14. Aircraft piston engine cooled by convection.

RADIATION

Conduction and convection cannot wholly account for some of the phenomena associated with heat transfer.

For example, the heat one feels when sitting in front of an open fire cannot be transferred by convection because the air currents are moving toward the fire. It cannot be transferred through conduction because the conductivity of the air is very small, and the cooler currents of air moving toward the fire would more than overcome the transfer of heat outward. Therefore, there must be some way for heat to travel across space other than by conduction and convection.

The existence of another process of heat transfer is still more evident when the heat from the sun is considered. Since conduction and convection take place only through some medium, such as a gas or a liquid, heat from the sun must reach the earth by another method, since space is an almost perfect vacuum. Radiation is the name given to this third method of heat transfer.

The term "radiation" refers to the continual emission of energy from the surface of all bodies. This energy is known as radiant energy. It is in the form of electromagnetic waves, radio waves, or x-rays, which are all alike except for a difference in wave length. These waves travel at the velocity of light and are transmitted through a vacuum more easily than through air because air absorbs some of them. Most forms of energy can be traced back to the energy of sunlight. Sunlight is a form of radiant heat energy that travels through space to reach the earth. These electromagnetic heat waves are absorbed when they come in contact with nontransparent bodies. The

result is that the motion of the molecules in the body is increased as indicated by an increase in the temperature of the body.

The differences between conduction, convection, and radiation may now be considered. First, although conduction and convection are extremely slow, radiation takes place at the speed of light. This fact is evident at the time of an eclipse of the sun when the shutting off of the heat from the sun takes place at the same time as the shutting off of the light. Second, radiant heat may pass through a medium without heating it. For example, the glass through which the sun's rays pass. Third, although heat transfer by conduction or convection may travel in roundabout routes, radiant heat always travels in a straight line. For example, radiation can be cut off with a screen placed between the source of heat and the body to be protected.

THERMODYNAMIC LAWS

The principle of conservation of energy can be stated as: energy can be neither created or destroyed. Alternately, this can be thought of as: the total energy in an isolated system remains constant. The first law of thermodynamics is an application of the fact that energy cannot be created or destroyed. It states that the change in internal energy of a system is equal to the heat added to the system minus the work done. In other words, there is a finite amount of heat (energy) in any closed system. If it increases, it is because it was added from outside the system. If it appears to decrease such as when the temperature decreases, that energy is accounted for by the work that is done by the system.

FIRST LAW

The first law of thermodynamics essentially eliminates the possibility of a perpetual motion machine. Any machine that produces work does so through conversion of energy the amount of which is finite either within the system or it is added from outside the system. However, the concept conveyed concerning the ability to transfer energy is invaluable in physics. Application of energy where and when it is needed makes aviation possible.

SECOND LAW

The second law of thermodynamics states: heat always flows from hot objects to cold objects, that is, from high energy toward low energy. Actually, this law is universal and included all types of energy. There is a tendency

towards an equilibrium of energy throughout the universe. Related is the tendency toward high entropy, which is basically randomness or high disorder.

The second law of thermodynamics guides the technician when understanding mechanical losses due to heat and friction. Much of the inefficiency of an engine is due to heat energy behavior as stated by the second law. Note that while this movement of energy is continuous and relentless, some measures can be taken to keep it under control and favorable. In other cases, the transfer of heat is manipulated to take advantage of this phenomenon.

GAS LAWS

The simple structure of gases makes them readily adaptable to mathematical analysis from which has evolved a detailed theory of the behavior of gases. This is called the kinetic theory of gases. The theory assumes that a body of gas is composed of identical molecules which behave like minute elastic spheres, spaced relatively far apart and continuously in motion.

The degree of molecular motion is dependent upon the temperature of the gas. Since the molecules are continuously striking against each other and against the walls of the container, an increase in temperature with the resulting increase in molecular motion causes a corresponding increase in the number of collisions between the molecules. The increased number of collisions results in an increase in pressure because a greater number of molecules strike against the walls of the container in a given unit of time.

If the container were an open vessel, the gas would expand and overflow from the container. However, if the container is sealed and possesses elasticity (such as a rubber balloon), the increased pressure causes the container to expand. For instance, when making a long drive on a hot day, the pressure in the tires of an automobile increases, and a tire which appeared to be somewhat "soft" in cool morning temperature may appear normal at a higher midday temperature. Such phenomena as these have been explained and set forth in the form of laws pertaining to gases and tend to support the kinetic theory.

BOYLE'S LAW

As previously stated, compressibility is an outstanding characteristic of gases. The English scientist, Robert Boyle, was among the first to study this characteristic that he called the "springiness of air." By direct measurement he discovered that when the temperature of a combined sample of gas was kept constant and the absolute pressure doubled, the volume was reduced to half the former value. As the applied absolute pressure was decreased, the resulting volume increased. From these observations, he concluded that for a constant temperature the product of the volume and absolute pressure of an enclosed gas remains constant. (*Figure 3-15*)

Boyle's law is normally stated: The volume of an enclosed dry gas varies inversely with its absolute pressure, provided the temperature remains constant. The following formula is used for Boyle's law calculations. Remember, pressure needs to be in the absolute.

$$\text{Volume 1} \times \text{Pressure 1} = \text{Volume 2} \times \text{Pressure 2}$$
$$\text{Or}$$
$$V_1P_1 = V_2P_2$$

Example: 10 ft³ of nitrogen is under a pressure of 500 psia. If the volume is reduced to 7 ft³, what will the new pressure be?

$$V_1P_1 = V_2P_2$$
$$10\,(500) = 7\,(P_2)$$
$$10\,(500) \div 7 = P_2$$
$$P_2 = 714.29 \text{ psia}$$

Force Pushing Down on Gas
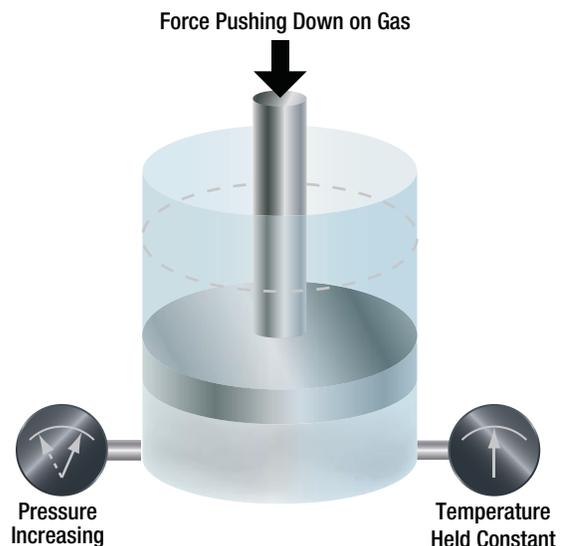
Pressure
Increasing

Temperature
Held Constant

Figure 3-15. Boyle's law example.

The useful applications of Boyle's law are many and varied. Some applications more common to aviation are: (1) the carbon dioxide (CO_2) bottle used to inflate life rafts and life vests; (2) the compressed oxygen and the acetylene tanks used in welding; (3) the compressed air brakes and shock absorbers; and (4) the use of oxygen tanks for high altitude flying and emergency use.

CHARLES' LAW

The French scientist, Jacques Charles, provided much of the foundation for the modern kinetic theory of gases. He found that all gases expand and contract in direct proportion to the change in the absolute temperature, provided the pressure is held constant.

As a formula, this law is shown as follows:

Volume 1 × Absolute Temperature 2 =
Volume 2 × Absolute Temperature 1
Or
V1T2 = V2T1

Charles' law also works if the volume is held constant, and pressure and temperature are the variables. In this case, the formula would be as follows:

P1T2 = P2T1

For this second formula, pressure and temperature must be in the absolute.

Example: A 15 ft³ cylinder of oxygen is at a temperature of 70 °F and a pressure of 750 psig. The cylinder is placed in the sun and the temperature of the oxygen increases to 140 °F. What would be the new pressure in psig?

70 degrees Fahrenheit = 530 degrees Rankine
140 degrees Fahrenheit = 600 degrees Rankine
750 psig + 14.7 = 764.7 psia
P1T2 = P2T1
764.7 (600) = P2 (530)
P2 = 764.7 (600) ÷ 530
P2 = 865.7 psia
P2 = 851 psig

GENERAL GAS LAW

By combining Boyle's and Charles' laws, a single expression can be derived which states all the information contained in both. The formula which is used to express the general gas law is as follows:

$$\frac{\text{Pressure (Volume 1)}}{\text{Temperature 1}} = \frac{\text{Pressure (Volume 2)}}{\text{Temperature 2}}$$

When using the general gas law formula, temperature and pressure must be in the absolute.

Example: 20 ft³ of the gas argon is compressed to 15 ft³. The gas starts out at a temperature of 60 °F and a pressure of 1 000 psig. After being compressed, its temperature is 90 °F. What would its new pressure be in psig?

60 degrees Fahrenheit = 520 degrees Rankine
90 degrees Fahrenheit = 550 degrees Rankine
1 000 psig + 14.7 = 1 014.7 psia
P1 (V1) (T2) = P2 (V2) (T1)
1 014.7 (20) (550) = P2 (15) (520)
P2 = 1 431 psia
P2 = 1 416.3 psig

DALTON'S LAW

If a mixture of two or more gases that do not combine chemically is placed in a container, each gas expands throughout the total space and the absolute pressure of each gas is reduced to a lower value, called its partial pressure. This reduction is in accordance with Boyle's law. The pressure of the mixed gases is equal to the sum of the partial pressures. This fact was discovered by Dalton, an English physicist, and is set forth in Dalton's law: "A mixture of several gases which do not react chemically exerts a pressure equal to the sum of the pressures which the several gases would exert separately if each were allowed to occupy the entire space alone at the given temperature."

IDEAL GAS LAW

The ideal gas law is used to describe the state of a gas under a given set of conditions such as temperature, pressure, and volume. Scientists and designers use this for a thorough analysis of the behavior of gases. The law assumes that gases are ideal, that is that the molecules are perfectly uniform and simply collide with each other but do not interact. It considers all of the energy to be the kinetic energy of the molecules bouncing of each

other. Therefore, any change in energy within the system also changes the temperature. This does not or is not actually the case when working with real gases.

WORK AND EXPANDING GASES

Work can be done by expanding gas. In fact, this is how energy in fuel is extracted in internal combustion engines. The fuel is combined with air and burned. The expanding gases from combustion in a reciprocating engine act upon the pistons forcing them downward. This rotates the crankshaft through the connecting rods. The rotating crankshaft turns the propeller. In a turbine engine, the expanding gases from combustion are directed through the turbine wheels. This rotates the engine shafts with the remaining gas pressure expelled rearward to produce thrust in the forward direction.

Adiabatic

In an adiabatic, or isolated system, when work is performed by expanding gases, the volume that the gases occupy increases but there is a corresponding decrease in temperature and pressure. With no energy added to the system since it is adiabatic, the values of pressure, temperature and volume could be calculated using the general gas formula shown above. If the gases are compressed instead of expanded, the phenomenon would reverse. A smaller volume would increase the pressure of the gas and increase the temperature of the gas.

Isothermal

An isothermal system is one in which temperature remains the same. When regarding expanding gases in such a system, the pressure and volume must vary inversely to each other. As volume increases (expansion of the gas), the pressure of the gas must decrease. Again, the opposite would hold that if the volume of the gases decreases the pressure of the gases increase in an isothermal system.

ENGINE CYCLES

CONSTANT VOLUME

The cycle through which a reciprocating engine operates is known as the Otto cycle. It is a constant volume cycle owing to a constant volume of fuel air mixture being burned during each cycle (2 revolutions of the crankshaft). Consider the diagram in *Figure 3-16*.

It shows a PV (pressure-volume) graph of a typical 4 stroke, Otto cycle engine. The cycle begins at the point labeled 1. This is the beginning of the intake stroke of the cycle. Both the volume and the pressure are at a minimum near atmospheric pressure. Between points 1 and 2, the piston is drawn out of the cylinder and the volume of air at atmospheric pressure increases as the suction caused by drawing the piston out of the cylinder pulls the fuel-air mixture into it. The compression stroke begins at point 2. The piston rises up in the cylinder
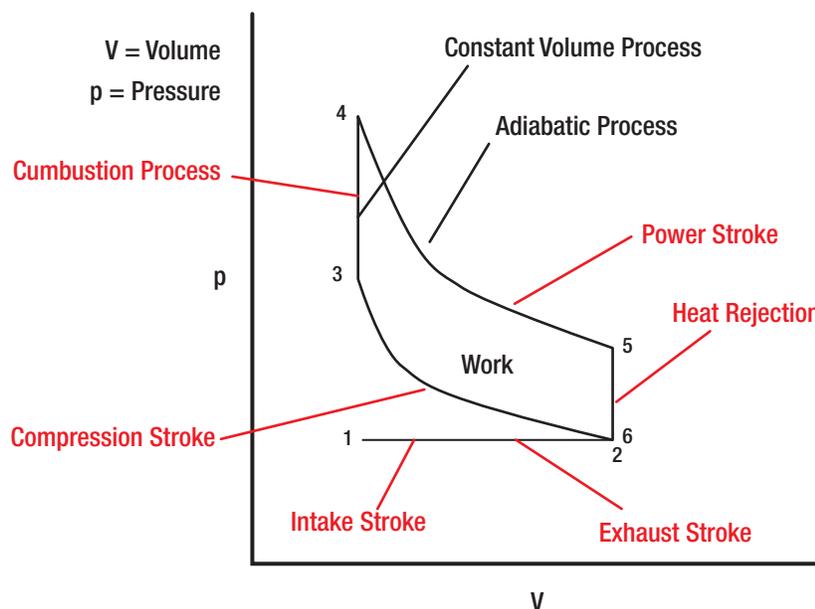

Figure 3-16. Constant volume engine cycle of a reciprocating internal combustion engine.

reducing the volume but increasing the pressure of the gas charge significantly. At point 3 on the graph, the intake valve and the exhaust valve are closed. A constant volume of gas is held in the combustion chamber as a spark from the spark plug ignites the mixture.

For the short duration that the fuel-air charge is burned, the volume remains constant but the energy released by burning the fuel causes a sharp increase in pressure (from points 3 to 4). The constant volume portion of the cycle ends when the piston passes top dead center in the cylinder and the power stroke begins at point 4. Between points 4 and 5, the pressure from the burned fuel-air mixture pushes the piston down transferring mechanical energy to the rotating crankshaft in the process. At point 5, the exhaust valve opens. Quickly, the pressure is reduced to atmospheric between points 5 and 6. Residual heat is given off and during the exhaust stroke between points 6 and 1, the piston moves back into the cylinder pushing all of the exhaust gas out thus returning the volume (and pressure) in the engine to their minimum values to begin the cycle again.

Notice that there is an area on the graph created by graphing the cycle. This represents the work done by the engine. For the purposes of this discussion, no accommodations have been made for the inefficiencies inherited in engine operation due to heat loss and friction. The actual work done by the engine would appear on the graph as a smaller area if these losses were included.

CONSTANT PRESSURE

A constant pressure engine cycle occurs in a turbine engine. The Brayton cycle is the name given to the thermodynamic cycle of a gas turbine engine to produce thrust. This is a variable volume constant-pressure cycle of events and is commonly called the constant-pressure cycle. A more recent term is "continuous combustion cycle." The four continuous and constant events are intake, compression, expansion (includes power), and exhaust. These cycles are discussed as they apply to a gas-turbine engine.

In the intake cycle, air enters at ambient pressure and a constant volume. It leaves the intake at an increased pressure and a decrease in volume. At the compressor section, air is received from the intake at an increased pressure, slightly above ambient, and a slight decrease in volume. Air enters the compressor where

it is compressed. It leaves the compressor with a large increase in pressure and decrease in volume, created by the mechanical action of the compressor. The next step, expansion, takes place in the combustion chamber by burning fuel, which expands the air by heating it.

The pressure remains relatively constant, but a marked increase in volume takes place. The expanding gases move rearward through the turbine assembly and are converted from velocity energy to mechanical energy by the turbine. The exhaust section, which is a convergent duct, converts the expanding volume and decreasing pressure of the gases to a final high velocity. The force created inside the engine to keep this cycle continuous has an equal and opposite reaction (thrust) to move the aircraft forward.

THERMAL EFFICIENCY

Any study of engines and power involves consideration of heat as the source of power. The heat produced by the burning of gasoline in the cylinders causes a rapid expansion of the gases in the cylinder, and this, in turn, moves the pistons and creates mechanical energy. It has long been known that mechanical work can be converted into heat and that a given amount of heat contains the energy equivalent of a certain amount of mechanical work. Heat and work are theoretically interchangeable and bear a fixed relation to each other. Heat can therefore be measured in work units (for example, ft-lb) as well as in heat units. The British thermal unit (BTU) of heat is the quantity of heat required to raise the temperature of 1 pound of water by 1 °F. It is equivalent to 778 ft-lb of mechanical work. A pound of petroleum fuel, when burned with enough air to consume it completely (heat of combustion), gives up about 20 000 BTU, the equivalent of 15 560 000 ft-lb of mechanical work. These quantities express the heat energy of the fuel in heat and work units, respectively.

The ratio of useful work done by an engine to the heat energy of the fuel it uses, expressed in work or heat units, is called the thermal efficiency of the engine. If two similar engines use equal amounts of fuel, the engine that converts into work the greater part of the energy in the fuel (higher thermal efficiency) delivers the greater amount of power. Furthermore, the engine that has the higher thermal efficiency has less waste heat to dispose of to the valves, cylinders, pistons, and cooling system of the engine. A high thermal efficiency also means

low specific fuel consumption and, therefore, less fuel for a flight of a given distance at a given power. Thus, the practical importance of a high thermal efficiency is threefold, and it constitutes one of the most desirable features in the performance of an aircraft engine.

Of the total heat produced, 25 to 30 percent is utilized for power output, 15 to 20 percent is lost in cooling (heat radiated from cylinder head fins), 5 to 10 percent is lost in overcoming friction of moving parts; and 40 to 45 percent is lost through the exhaust. Anything that increases the heat content going into mechanical work on the piston, which reduces the friction and pumping losses, or which reduces the quantity of unburned fuel or the heat lost to the engine parts, increases the thermal efficiency.

The portion of the total heat of combustion that is turned into mechanical work depends to a great extent upon the compression ratio. The compression ratio is the ratio of the piston displacement plus combustion chamber space to the combustion chamber space, as mentioned earlier. Other things being equal, the higher the compression ratio is, the larger is the proportion of the heat energy of combustion turned into useful work at the crankshaft. On the other hand, increasing the compression ratio increases the cylinder head temperature. This is a limiting factor because the extremely high temperature created by high compression ratios causes the material in the cylinder to deteriorate rapidly and the fuel to detonate instead of burning at a controlled rate.

The thermal efficiency of an engine may be based on either BHP or indicated horsepower (IHP) and is represented by the formula:

$$\frac{IHP \times 33\,000}{Weight\ of\ Fuel\ Burned/min. \times Heat\ Value \times 778}$$

The formula for brake thermal efficiency is the same as shown above, except the value for bhp is inserted instead of the value for IHP.

Example: An engine delivers 85 BHP for a period of 1 hour and during that time consumes 50 pounds of fuel. Assuming the fuel has a heat content of 18 800 BTU per pound, find the thermal efficiency of the engine:

$$\frac{85\ IHP \times 33\,000}{.833 \times 18\,800\ BTU \times 778} = \frac{2\,805\,000}{12\,183\,791}$$

Brake thermal efficiency = 0.23 or 23 percent

Reciprocating engines are only about 34 percent thermally efficient; that is, they transform only about 34 percent of the total heat potential of the burning fuel into mechanical energy.

REFRIGERATION AND HEAT PUMPS

Previously, the second law of thermal dynamics stated that heat energy always flows from high energy to low energy or, from hot to cold. Since this is the case, a means for manipulating this and other natural laws of energy transfer must be used in order to cool something. Refrigeration is such a means.

An air conditioning system, for example, cools the cabin of an aircraft on a hot day. Since the elevated ambient temperature outside the aircraft is what caused the cabin to be hot in the first place, simply moving the cabin air outside is not a solution. The replacement air comes from ambient air which is known to be too hot.

Vapor cycle air conditioning is used on older transport category aircraft and on many business and general aviation aircraft. This is the same type of air conditioning in your car, home or refrigerator. (*Figure 3-17*)
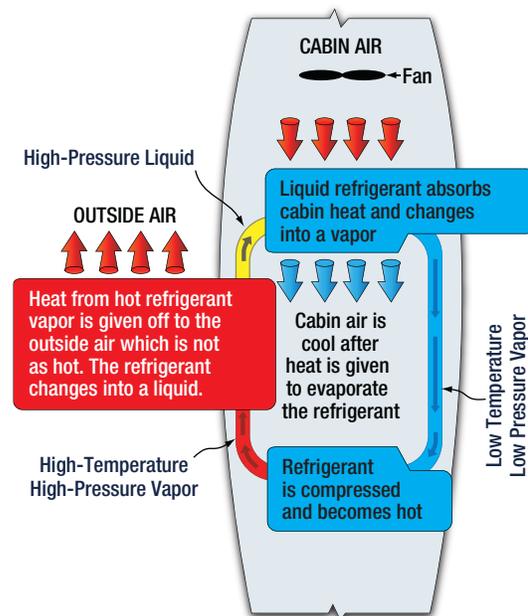

Figure 3-17. In vapor cycle air conditioning, heat is carried from the cabin to the outside air by a refrigerant which changes from a liquid to a vapor and back again.

Energy can be neither created nor destroyed; however, it can be transformed and moved. This is what occurs during vapor cycle air conditioning. Heat energy is moved from the cabin air into a liquid refrigerant. Due to the additional energy, the liquid changes into a vapor. The vapor is compressed and becomes very hot. It is removed from the cabin where the very hot vapor refrigerant transfers its heat energy to the cooler outside air. In doing so, the refrigerant cools and condenses back into a liquid. The refrigerant returns to the cabin to repeat the cycle of energy transfer.

LATENT HEAT

One of the keys to the operation of an air conditioning system is latent heat. Adding heat to a substance does not always raise its temperature. When a substance changes state, such as when a liquid changes into a vapor, heat energy is absorbed. This heat energy absorbed to change state is called latent heat. When a vapor condenses into a liquid, this latent heat energy is given off.

The temperature of a substance remains constant during its change of state. All energy absorbed or given off, the latent heat, is used for the change of state process. After the change of state is complete, heat added to a substance raises the temperature of the substance.

When a liquid changes state and becomes a vapor, the process is known as evaporation. The heat energy absorbed to change from liquid to a gas is known as the latent heat of vaporization. If a substance is condensing, that is, changing from a gas to a liquid, the heat energy given off is sometimes known as the latent heat of fusion. Substances have characteristic amounts of energy required to change state. They also change state at different temperatures. The boiling point of a substance is the temperature at which the substance changes state from a liquid to a vapor. The boiling point changes with the amount of pressure applied to the substance. Refrigerants used in air conditioning systems typical boil at very low temperatures.

Another device that moves heat energy is a heat pump. A heat pump is a device that moves heat energy from one location to another. It is typically used for moderate temperature adjustments. Like a vapor cycle air conditioner, the second law of thermal dynamics is used to advantage. A circulating refrigerant absorbs heat from a warm area and moves it to a cooler area where it

is released. Usually, a heat pump is reversible so that heat can be moved from the area that was a heat sink when that area becomes hot and the normal area to be cooled requires to be heated.

THERMAL ENERGY

All matter not existing at absolute zero temperature has thermal energy. The extent of vibration or internal movement of the molecules of a substance is actually what is referred to as thermal energy. Usually, thermal energy is regarded for an entire body or system. Therefore it is not the same as temperature. A cup of boiling water, for example, would contain less thermal energy than a swimming pool full of water at 25 °C.

HEAT OF COMBUSTION

The term heat of combustion refers to the energy released as heat when the fuel air mixture is burned in an internal combustion engine. This is a theoretical value that can be calculated and is characteristic for each particular compound of fuel. Heat of combustion is typically measured in mega-joules per kilogram or in BTU's per pound.

Question: 3-1

Thermodynamics is the branch of physical science that deals with the relationship between _____ and other forms of energy.

Question: 3-2

What denomination(s) are used to express heat energy?

Question: 3-3

What is the principle upon which an electric resistance thermometer operates?

Question: 3-4

Name 3 ways heat can be transferred.

Question: 3-5

What does the second law of thermodynamics state?

Question: 3-6

What three variables of a gas are consider when applying the general gas law? (Hint: The general gas law combines Boyle's law and Charles' law.)

Question: 3-7

Measured in mega-joules per kilogram or BTU's per pound what term is given to the calculated theoretical value of the energy released as heat in an internal combustion engine?

Question: 3-8

When heat is added to a substance, the temperature rises. This statement is:
  A. True all of the time.
  B. True some of the time.
  C. Never known for certain.

ANSWERS

Answer: 3-1

heat.

Answer: 3-2

Imperial System: BTU (British Thermal Units), calories SI/Metric: joules, calories.

Answer: 3-3

When the temperature changes, the resistance of a material changes.

Answer: 3-4

Conduction.
Convection.
Radiation.

Answer: 3-5

Heat always flows from high energy to low energy (or, heat always flows from hot to cold).

Answer: 3-6

Temperature.
Pressure.
Volume.
The general gas law is:

$$\frac{\text{Pressure (Volume 1)}}{\text{Temperature 1}} = \frac{\text{Pressure (Volume 2)}}{\text{Temperature 2}}$$

Answer: 3-7

Heat of combustion.

Answer: 3-8

true some of the time.

PART-66 SYLLABUS LEVELS

CERTIFICATION CATEGORY → | **B1** | **B2**

Sub-Module 04
OPTICS (LIGHT)
Knowledge Requirements

2.4 – Optics (Light)
Nature of light; speed of light;
Laws of reflection and refraction: reflection at plane surfaces, reflection by spherical mirrors, refraction, lenses;
Fiber optics.

B1	B2
2	2

OPTICS (LIGHT)

AIRCRAFT
TECHNICAL
BOOK COMPANY

2.4 - OPTICS
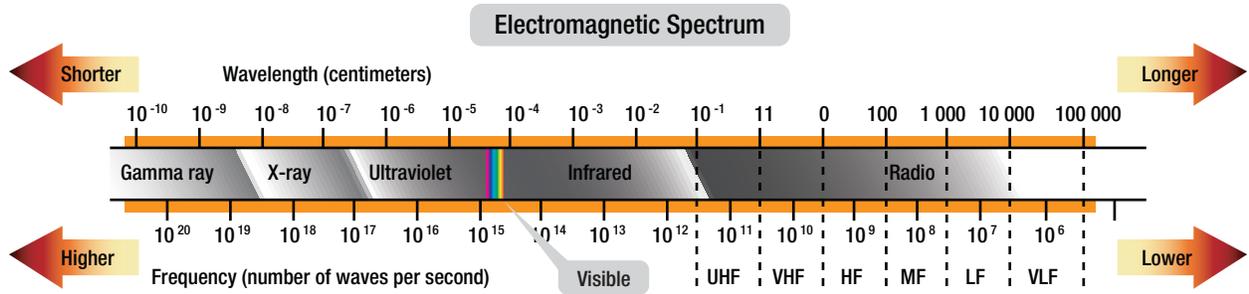
Figure 4-1. Radio waves are just some of the electromagnetic waves found in space.

THE NATURE OF LIGHT

Light is a form of electromagnetic radiation. It is part of the wide spectrum of electromagnetic radiation that surrounds us at all times. Visible light is a relatively small part of the spectrum. (*Figure 4-1*)

SPEED OF LIGHT

Light is a type of wave. As in the case of all wave motion, the wave moves with a definite speed. The speed of light (c) is exactly 299 792 458 meters per second which is 186 282.4 miles per second. It should be noted that this is the speed of light in a vacuum. The passage of light through matter reduces this speed. Materials have a refractive index (n) which is the speed of light (c) in a vacuum divided by the speed of light through the material (v). The refractive index of air is 1.000 29. The refractive index of water is 1.33 and approximately 1.6 for glass. This means that light travels slower through water than air and slower through glass than water.

The wavelength of visible light is usually measured in a unit called the Angstrom (A): $1A = 10^{-10}$m. Various colors of visible light have characteristic wavelengths. They also have characteristic frequencies since the frequency of light × wavelength = speed of light. With symbols this is written $f\lambda = c$. *Figure 4-1* lists various colors of light and their respective wavelengths.

Wavelengths of visible light.
- Violet = 4 500 A
- Blue = 4 800 A
- Green = 5 200 A
- Yellow = 5 800 A
- Orange = 6 000 A
- Red = 6 400 A

REFLECTION

Reflection is a change in direction of a lightwave when it strikes a different media than that in which it was traveling so that the wave returns back into the original media. Mirror-like reflection is called specular reflection. This can occur when the reflective surface is a material that suppresses the propagation of the light wave or in a material that allows the passage of light such as water or glass. Specular reflection is shown in *Figure 4-2*.

A perpendicular line drawn from the point where the light strikes the mirror is called the normal. The light striking the mirror forms an angle of incidence (Øi) with the normal. The light reflected from the mirror also forms an angle with the normal called the angle of reflection (Ør). It is a law of reflection that the angle of incidence is equal to the angle of reflection. Two further laws of reflection are: the incidence ray, the reflective ray and the normal at the point of incidence lie in the same plane, and the reflected ray and the incidence ray are on opposite sides of the normal.
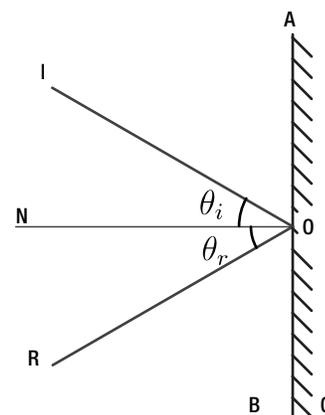

Figure 4-2. Specular reflection.

Reflection can occur off of a plane surface such as a typical flat mirror or piece of glass. It can also occur off of a curved surface. When reflection occurs off of a flat surface, it is said to form a mirror image. When occurring off of a curved surface the image may be magnified or demagnified.

Most curved mirrors are spherical. They can be convex (bulging outward toward the light source) or concave (bulging inward away from the light source). A convex mirror reflects light outward and demagnifies the image. It also provides a wider field of view. Convex mirrors are commonly used as passenger-side rear-view mirrors on automobiles. A concave mirrors focuses light when it reflects. The image it reflects depends on the distance away from the surface. Generally, a concave mirror is used so that it magnifies the image. It can be found in telescopes and in make-up mirrors to gain a close look at one's face. (*Figure 4-3*)

REFRACTION

Refraction is the phenomenon observed when light changes direction due to it passing through a medium in which it travels at an altered speed. When light enters a slower medium at an angle, its frequency remains the same. This is established at the source of the light. But as soon as part of the incoming light ray reaches a slower medium, its wavelength is shortened and the light bends towards the normal line. The amount of bend depends of the speed of light through the medium. The slower the speed, the more light will bend.

As previously mentioned, materials have a refractive index which compares the speed of light through a vacuum to the speed of light through the material. The higher the refractive index, the slower the speed of light through the material.

Using information about how light will pass through a medium enables the production of optic lenses. Snell's Law provides a mathematical equation for determining the angle that light will refract when passing from one medium through another:

$$\frac{n_1}{n_2} = \frac{\sin\emptyset_2}{\sin\emptyset_1}$$

In this equation; n_1 is the index of refraction of the first medium and n_2 is the index of refraction of the second medium through with the light will pass and bend. The angles are measured from the normal.

LENSES

Because light can be directed at different angles using various mediums, lenses are developed to focus light so that it is beneficial. Eye glasses are made so that the incoming light will be corrected so that it focuses the image of the object being looked at directly on the retina of the eye.

A lens can be defined as any device that transmits and refracts light. Note that some lenses are constructed to focus electromagnetic waves that are not visible light such as microwaves. A lens can be simple, causing a single refraction of light, or compound, consisting of more than one simple lens. Compound lenses are used to refine the focus and eliminate aberrations. An aberration
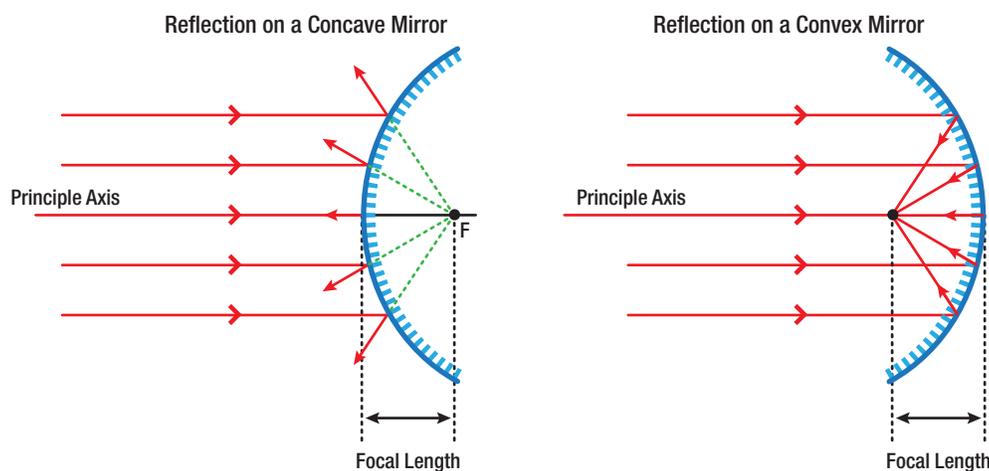
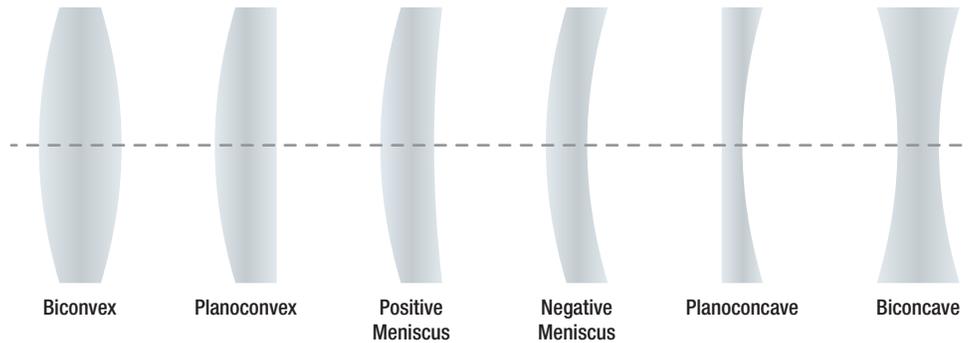Figure 4-3. Reflection patterns of light on a concave and convex mirrored surface.

Figure 4-4. A sample of different shaped lenses.

| Biconvex | Planoconvex | Positive Meniscus | Negative Meniscus | Planoconcave | Biconcave |

in optics is the failure of rays to converge at a single focus point because of the limitations or defects in the lens. In addition to the material a lens is made from, the shape of a lens also factors in to the direction and focus of light passing through it. (*Figure 4-4*)

Similar to mirrors, lenses are often ground spherically. A lens that bulges outward from the lens is convex, a lens that curves into the lens is concave. Variations exist. Advanced optic manufacturing technology now allows the creation of aspheric lenses (non-spherical).

FIBER OPTICS

Fiber optics is the branch of optical technology concerned with the transmission of light through fibers. Electrical data is converted to optical signals and sent through optical fibers at the speed of light. The transmission of data through optical fibers offers wide bandwidth, light weight, and freedom from electromagnetic influence. (*Figure 4-5*)

CABLE CONSTRUCTION

A fiber's cladding is usually coated with a tough buffer layer which may be further surrounded by a glass jacket layer. These layers add strength to the fiber but do not contribute to its optical properties. Fiber bundles sometimes put light-absorbing material between the fibers to prevent light that leaks out of one fiber from entering another. (*Figure 4-6*)

Fiber cable can be very flexible, but optical loss increases greatly if the fiber is bent to a radius smaller than around 30 mm, creating problems if the cable is bent around corners or wound around a spool. Some fiber optic cables are reinforced with glass yarns to increase strength and also to protect the cable core against rodents and insects.

Figure 4-5. Fiber optic cable bundle.
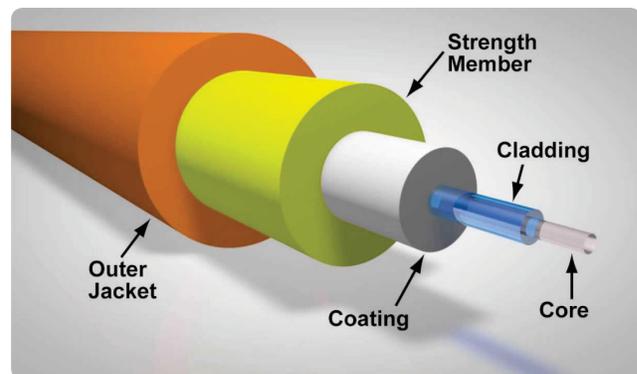
Figure 4-6. Construction of a fiber optic cable.

FIBER MODES

Single-mode (or mono-mode) fiber has a core diameter less than about ten times the wavelength of the propagating light and can process only a single signal at a time. Most single-mode fiber is designed for use in the near infrared portion of the light spectrum.

Fiber with a core diameter greater than 10 micrometers is called multi-mode fiber. In multi-mode fiber, multiple rays of light are guided along the fiber core by the internal reflection of the cladding surrounding the fiber. Each light pulse carries its own piece of data and is transmitted through the cable at different angles so as not to interfere with other pulses traveling through the same cable. Rays that reflect from the cladding at

angles greater than the critical angle are completely reflected. Rays that meet the boundary at a lower angle are refracted into the cladding, and do not convey light or information along the fiber. (*Figures 4-7 and 4-8*)

Attenuation in fiber optics, also known as transmission loss, is the reduction in intensity of the light beam as it travels through the fiber medium. Attenuation is caused by both scattering and absorption within the fiber and is an important factor limiting the transmission of a signal across large distances. Much research has gone into limiting attenuation. It has been said that if ocean water was as clear as single-mode fiber, one could see all the way to the bottom of the Marianas Trench in the Pacific Ocean, a depth of 36 000 feet.

TERMINATION AND SPLICING

Optical fibers are connected to terminal equipment by optical fiber connectors. (*Figure 4-9*) Standard connectors provide a physical contact where the mating surfaces touch each other at an angled surface to achieve the lowest possible attenuation and reduced reflections.

A fiber-optic connector is basically a rigid cylindrical barrel surrounded by a sleeve that holds the barrel in its mating socket. A typical connector is installed by preparing the fiber end and inserting it into the rear of the connector body. Quick-set adhesive is usually used to hold the fiber securely, and a strain relief is secured to the rear. Once the adhesive sets, the fiber's end is polished to a mirror finish. Various polish methods are used, depending on the type of fiber and the application. For single-mode fiber, fiber ends are polished with a slight curvature that makes the mated connectors touch only at their cores. This is called a physical contact (PC) polish. Such connections have higher loss than PC connections, but greatly reduce back reflection, because light that reflects from the angled surface leaks out of the fiber core.

Optical fibers may be connected to each other by connectors or by splicing; that is, joining two fibers together to form a continuous waveguide. The generally accepted splicing method is known as arc fusion splicing, which melts the fiber ends together with an electric arc. For quicker fastening jobs, a mechanical splice can also be used.
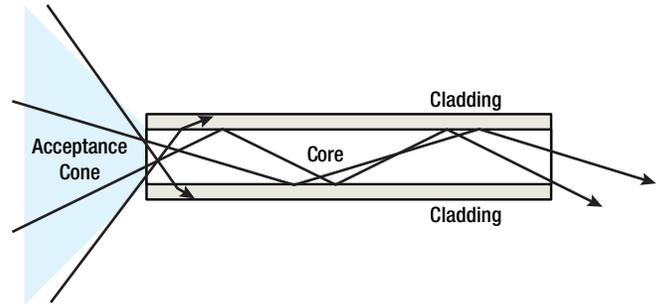
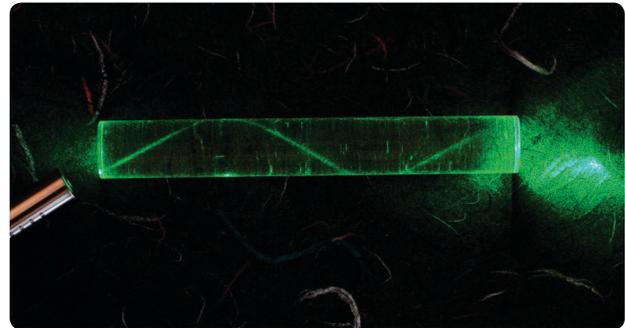Figure 4-7. Propagation of light through a multimode optical fiber.

Figure 4-8. A laser bouncing through an acrylic rod illustrating the reflection of light in a multimode optical fiber.
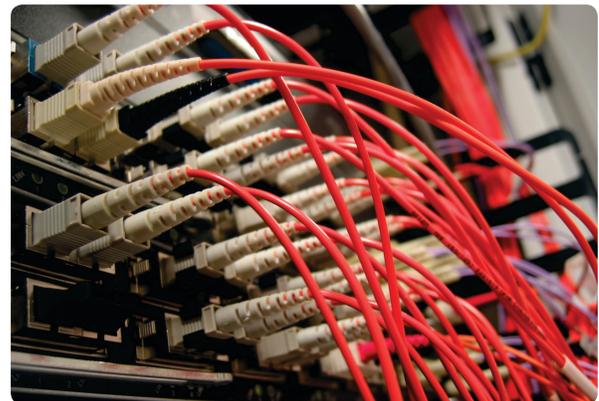

Figure 4-9. Fiber optic cable connections into a data panel.

In fusion splicing, the two cable ends are fastened inside a splice enclosure and the fiber ends are stripped of their protective coating and outer jacket. The ends are cleaved with a precision cutter and are placed in the splicer. The splice area is inspected via a magnified view screen to check the cleaves before and after the splice. The splicer then emits a small spark at the gap to burn off dust and moisture. Then the splicer generates a larger spark that fuses the ends together permanently. The optical loss due to the splice is measured by directing light through the cladding on one side and measuring light leaking from the cladding on the other. A splice loss of optical clarity under 0.1 dB is typical.
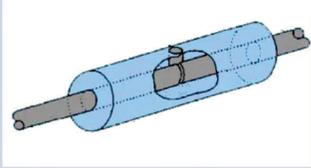
Mechanical Splicing	Fusion Splicing
1. Just a mechanical alignment device 2. Holds the fiber ends in a precisely aligned position. 3. Still two separate fibers. Not continuous.	1. Two fiber ends are aligned and then fused together with heat or electric arc. 2. Two fibers become continuous.

Figure 4-10. Mechanical and fusion splicing techniques.

Mechanical splices are designed to be quicker and easier to install, but there is still the need for stripping, careful cleaning and precision cleaving. The fiber ends are aligned and held together by a sleeve, often using a clear gel that enhances the transmission of light across the joint. Mechanical splices typically have higher optical loss and are less robust than fusion splices, especially if the gel is used. (***Figure 4-10***)

Military aircraft have used fiber optics for heads up displays. (***Figure 4-11***).

The Boeing 777 uses some fiber optics transmission line for its inflight entertainment systems and expanded use of fiber optics is promised. Some basic advantages of fiber optics for data transmission include:
- System Performance
- Greatly Increased Bandwidth and Capacity
- Lower Signal Attenuation (Loss)
- Immune to Noise (Electromagnetic Interference) and Radio-Frequency Interference
- No Crosstalk
- Lower Bit Error Rates
- Signal Security
- Difficult To Tap
- Nonconductive Electrical Isolation (Does Not Radiate Signals)
- No Common Ground Required
- Freedom From Short Circuit and Sparks
- Reduced Size and Weight of Cables
- Environmental Protection
- Resistant to Radiation and Corrosion
- Resistant to Temperature Variation

Figure 4-11. Fiber optic heads up display.

Important deterrents are high cost and the reliability of connectors in the harsh aviation operating environments.

FIBER OPTIC DATA LINK

Fiber optic data link is the name given to the system of components that use optical fibers for the transmission of data. Data is input to a transmitter which converts the electric signals into optical signals and directs them into the fiber. The transmitter's drive circuit converts the electric signal to an optical signal by varying the electric current through the light source. LED's (light emitting diodes) and laser diodes are two common light sources employed. A secure, reliable and durable connector is required to join the transmitter and the fiber. At the remote end of the fiber, another connector joins the fiber to a receiver. The receiver transforms the optical signal back into an electrical signal for use.

As stated, the cost and availability of easy to manipulate, reliable and durable connectors have limited the use of fiber optics in aviation to this point. Conversely, the demand for high performance, bandwidth and weight savings free from electromagnetic interference is driving development of fiber optic use in aircraft. While many experts believe the use of copper and aluminum alongside fiber optics has an enduring future, developers are hard at work addressing the shortcomings of fiber optic transmission. Controlling primary functions of aircraft operation (i.e. landing gear, flight controls, system operations, etc.) may someday be performed with fiber optic data links. (*Figure 4-12*)
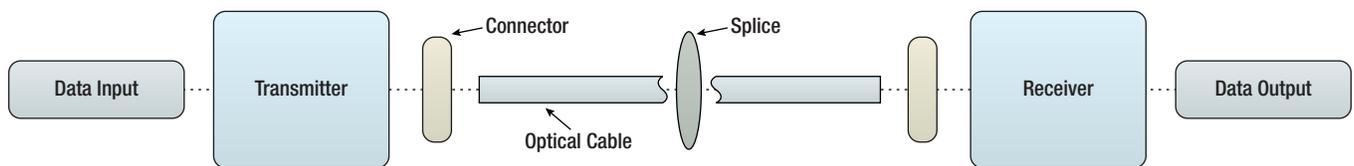
Figure 4-12. Typical components of a fiber optic data link.

Question: 4-1

What is a refractive index?

Question: 4-2

The change of direction of light when it flows through a media is known as _____.

Question: 4-3

Name three advantages of transmitting data through optical fibers.

Question: 4-4

What causes light within a fiber optic cable to maintain its direction?

Question: 4-5

What two advantages of fusion splicing of a fiber optic cable over mechanical splicing?

Question: 4-6

Where within a fiber optic cable is the greatest amount of light lost?

ANSWERS

Answer: 4-1
The speed at which light travels through a substance divided by the speed of light in a vacuum.

Answer: 4-2
refraction.

Answer: 4-3
Wide bandwidth, light weight, and freedom from electromagnetic influence.

Answer: 4-4
The reflective cladding surrounding the fiber's core.

Answer: 4-5
Less optical loss and a stronger splice.

Answer: 4-6
At splice joints and connection terminals.

PART-66 SYLLABUS	LEVELS	
CERTIFICATION CATEGORY →	**B1**	**B2**

Sub-Module 05

WAVE MOTION AND SOUND

Knowledge Requirements

2.5 – Wave Motion and Sound

Wave motion: mechanical waves, sinusoidal wave motion, interference phenomena, standing waves;
Sound: speed of sound, production of sound, intensity, pitch and quality, Doppler effect.

2 **2**

WAVE MOTION AND SOUND

2.5 - WAVE MOTION AND SOUND

WAVE MOTION

In physics, a wave is an oscillation accompanied by a transfer of energy. Frequency refers to the addition of time. Wave motion transfers energy from one point to another, which displace particles of the transmission medium–that is, with little or no associated mass transport. Waves consist, instead, of oscillations or vibrations around almost fixed locations.

MECHANICAL WAVES

A mechanical wave is a wave that is an oscillation of matter, and therefore transfers energy through a medium. While waves can move over long distances, the movement of the medium of transmission (the material) is limited. Therefore, the oscillating material does not move far from its initial position. Mechanical waves transport energy which propagates in the same direction as the wave. Mechanical waves can be produced only in media which possess elasticity and inertia.

A mechanical wave requires an initial energy input. Once this energy is added, the wave travels through the medium until all its energy is transferred. In contrast, electromagnetic waves require no medium, but can still travel through one.

An important property of mechanical waves is that their amplitudes are measured in an unusual way; by displacement of the medium divided by its wavelength. When this gets comparable to unity, significant effects such as harmonic generation may occur, and if large enough, may result in chaotic effects. For example, waves on the surface of a body of water break when this dimensionless amplitude exceeds 1, resulting in a foam on the surface and turbulent mixing. Some of the most common examples of mechanical waves are water waves, sound waves, and seismic waves. There are three types of mechanical waves: transverse waves, longitudinal waves, and surface waves.

Transverse Waves
Transverse waves cause the medium to vibrate at a right angle to the direction of the wave. Transverse waves have two parts; the crest and the trough. The crest is the highest point of the wave and the trough is the lowest. Its wavelength is the distance from crest to crest or from trough to trough.

To see an example, move an end of a Slinky (whose other end is fixed) to the left-and-right, as opposed to to-and-fro. (**Figure 5-1**) Light also has properties of a transverse wave, although it is an electromagnetic wave.

Longitudinal Waves
Longitudinal waves cause the medium to vibrate parallel to the direction of the wave. It consists of multiple compressions and rarefactions. The rarefaction is the farthest distance apart in the longitudinal wave and the compression is the closest distance together. The speed of the longitudinal wave is increased due to the closer proximity of the atoms in the medium that is being compressed. Sound is considered a longitudinal wave.

Surface Waves
This type of wave travels along a surface that is between two media. An example of a surface wave would be waves in a pool, the ocean any other body of water. (**Figure 5-2**)

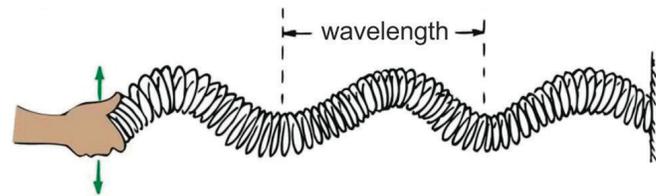There are two types of surface waves; Rayleigh waves and Love waves.

Figure 5-1. A Slinky toy demonstrates the pattern of a transverse wave.

Figure 5-2. Example of a surface wave would be waves in a pool, the ocean any other body of water.

Rayleigh waves, also known as ground roll, are waves that travel as ripples similar to waves on the surface of water. A Love wave is a surface waves having horizontal waves that are shear or transverse to the direction of movement. They usually travel faster than Rayleigh waves and have the largest amplitude.

ELECTROMAGNETIC WAVES

The second main wave type, electromagnetic waves, do not require a medium. Instead, they consist of periodic oscillations of electrical and magnetic fields which are generated by charged particles, and can therefore travel through a vacuum. These wave types include radio waves, microwaves, infrared radiation, visible light, ultraviolet radiation, X-rays and gamma rays.

A electromechanical wave can be transverse, where a disturbance creates oscillations that are perpendicular to the propagation of energy transfer, or longitudinal where the oscillations are parallel to the direction of energy propagation. While mechanical waves can be both transverse and longitudinal, all electromagnetic waves are transverse in free space.

SINUSOIDAL WAVE MOTION

A sine wave or sinusoid is a mathematical curve that describes a smooth repetitive oscillation. A sine wave is a continuous wave. (*Figure 5-3*)

The sine wave is important in physics because it retains its wave shape when added to another sine wave of the same frequency. It is the only periodic waveform that has this property. The human ear can recognize single sine waves as sounding clear because sine waves are representations of a single frequency without harmonics.
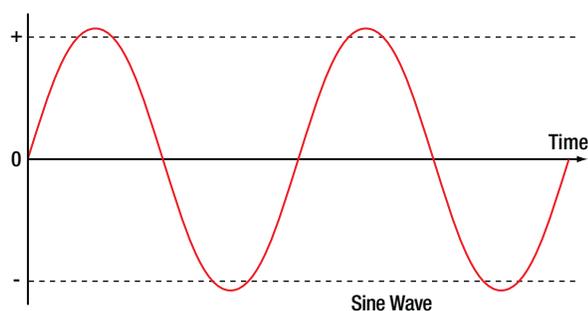
Figure 5-3. A sine wave is a steady wave with repeating amplitude and frequency.

INTERFERENCE PHENOMENA

Wave interference is the effect of combining two or more waves moving on intersecting paths. The effect is of combining the amplitudes of each individual waves.

If both waves are of the same frequency and phase (they move at the same rate), the amplitudes are reinforced, producing constructive interference. However if the two waves are out of phase, the result is destructive, producing complete annulment. For example, if two stones are dropped in a pool of water, waves spread out from each source, and interference occurs where they combine. Constructive interference results where the crest of one coincides with the crest of the other.

Interference also occurs between two waves moving in the same direction but having different wavelengths or frequencies. The effect is a complex wave. A pulsating frequency called a beat results when the wavelengths are slightly different. Interference between waves traveling in opposite directions produce standing waves.

STANDING WAVES

A standing wave (or stationary wave) is a wave in which its peaks do not move spatially. The amplitude of the wave at a point in space may vary, but its phase remains constant. The locations at which the amplitude is smallest are called nodes, and the locations where the amplitude is greatest are called antinodes.

Standing waves were first noticed on the surface of a liquid in a vibrating container. It occurs because the medium is moving in the opposite direction to the wave, or as a result of interference between two waves traveling in opposite directions.

The most common cause of standing waves is resonance, in which standing waves occur due to interference between waves reflected back and forth at the same frequency. For waves of equal amplitude traveling in opposing directions, there is no net propagation of energy.

SOUND

Sound has been defined as a series of disturbances in matter that the human ear can detect. This definition can also be applied to disturbances which are beyond the range of human hearing. There are three elements which are necessary for the transmission and reception of

AIRCRAFT TECHNICAL BOOK COMPANY

sound. These are the source, a medium for carrying the sound, and the detector. Anything which moves back and forth (vibrates) and disturbs the medium around it may be considered a sound source.

An example of the production and transmission of sound is the ring of a bell. When the bell is struck and begins to vibrate, the particles of the medium (the surrounding air) in contact with the bell also vibrate. The vibrational disturbance is transmitted from one particle of the medium to the next, and the vibrations travel in a "wave" through the medium until they reach the ear. The eardrum, acting as detector, is set in motion by the vibrating particles of air, and the brain interprets this vibration as the sound of the bell.

SOUND WAVES

Sound waves are mechanical waves since sound is a wave motion in matter. It can best be understood by first considering water waves. When an object is thrown into a pool, a series of circular waves travel away from the disturbance. In *Figure 5-4* such waves are seen from a top perspective, with the waves traveling out from the center. In the cross-section perspective in *Figure 5-4*, notice that the water waves are a succession of crests and troughs. The wavelength is the distance from the crest of one wave to the crest of the next. Water waves are known as transverse waves because the motion of the water molecules is up and down, or at right angles to the direction in which the waves are traveling. This can be seen by observing a cork on the water, bobbing up and down as the waves pass by.

Sound travels through matter in the form of longitudinal wave motions. These waves are called longitudinal waves because the particles of the medium vibrate back and forth longitudinally in the direction of propagation.

When the tine of a tuning fork moves in an outward direction, the air immediately in front of the tine is compressed so that its momentary pressure is raised above that at other points in the surrounding medium. Because air is elastic, this disturbance is transmitted progressively in an outward direction from the tine in the form of a compression wave. (*Figure 5-5*)

When the tine returns and moves in an inward direction, the air in front of the tine is rarefied so that its momentary pressure is reduced below that at other points in the surrounding medium. This disturbance is transmitted in the form of a rarefaction (expansion) wave and follows the compression wave through the medium.

The progress of any wave involves two distinct motions: (1) The wave itself moves forward with constant speed, and (2) simultaneously, the particles of the medium that convey the wave vibrate harmonically. Examples of harmonic motion are the motion of a clock pendulum, the balance wheel in a watch, and the piston in a reciprocating engine. As the longitudinal sound wave progresses out from its source, another pattern can be discerned 90 degrees to the longitudinal wave. This transverse amplitude wave is sinusoidal as the vibration varies between maximum and minimum amplitude.

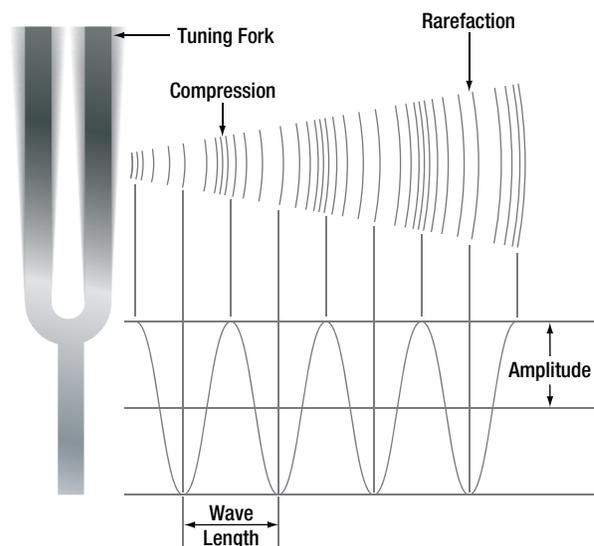Figure 5-4. Relationship between sound and waves in water.

Figure 5-5. Sound propagation by a tuning fork.

When two or more sound waves overlap or combine they demonstrate interference phenomena. If the waves arrive at the listener in phase, they will enhance and the sound disturbance is larger. If the waves arrive out of phase, they will partially cancel each other out. A distinctive interference pattern of large and then small repeating disturbances is heard. Sound canceling headphones take advantage of this type of interference phenomena. As sound reaches the headset, an out of phase interference wave is created. It is broadcast in the set so that the original sound wave and the broadcast wave interfere and the wave disturbance is reduce to nearly nothing.

SPEED OF SOUND

In any uniform medium, under given physical conditions, sound travels at a definite speed. In some substances, the velocity of sound is higher than in others. Even in the same medium under different conditions of temperature, pressure, and so forth, the velocity of sound varies. Density and elasticity of a medium are the two basic physical properties which govern the velocity of sound.

In general, a difference in density between two substances is sufficient to indicate which one will be the faster transmission medium for sound. For example, sound travels faster through water than it does through air at the same temperature. However, there are some surprising exceptions to this rule of thumb. An outstanding example among these exceptions involves comparison of the speed of sound in lead and aluminum at the same temperature. Sound travels at 16 700 fps in aluminum at 20 °C, and only 4 030 fps in lead at 20 °C, despite the fact that lead is much more dense than aluminum. The reason for such exceptions is found in the fact, mentioned above, that sound velocity depends on elasticity as well as density.

Using density as a rough indication of the speed of sound in a given substance, it can be stated as a general rule that sound travels fastest in solid materials, slower in liquids, and slowest in gases. The velocity of sound in air at 0 °C (32 °F) is 1 087 fps and increases by 2 fps for each degree Celsius of temperature rise (1.1 fps for each degree Fahrenheit).

Mach Number

In the study of aircraft that fly at supersonic speeds, it is customary to discuss speed in relation to the speed of sound of 1 223 kph (760 mph) at 15 °C (59 °F). The term "Mach number" has been given to the ratio of the speed of an aircraft to the speed of sound, in honor of Ernst Mach, an Austrian scientist. If the speed of sound at sea level is 1 223 kph, an aircraft flying at a Mach number of 1.2 at sea level would be traveling at a speed of 1 223 kph × 1.2 = 1 467 kph.

PRODUCTION OF SOUND

Sound is produced when something vibrates. The vibrating body causes the medium (water, air, etc.) around it to vibrate. Vibrations in air are called traveling longitudinal waves, which we can hear. Sound waves consist of areas of high and low pressure called compressions and rarefactions. *Figure 5-6* is a traveling wave. The shaded bar above it represents the varying pressure of the wave. Lighter areas are low pressure (rarefactions) and darker areas are high pressure (compressions).

One wavelength of the wave is highlighted in red. This pattern repeats indefinitely. The wavelength of voice is about one meter long. The wavelength and speed of the wave determine the pitch, or frequency of the sound. Since sound travels at 343 meters per second at standard
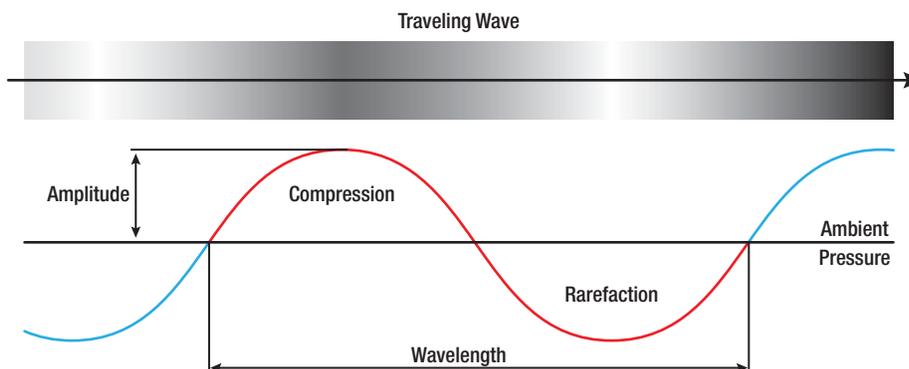
Figure 5-6. The various components of a sound wave.

temperature and pressure, speed is a constant. Thus, frequency is determined by speed/wavelength. The longer the wavelength, the lower the pitch. The 'height' of the wave is its amplitude. The amplitude determines how loud a sound will be. Greater amplitude means the sound will be louder.

SOUND INTENSITY

Sound intensity is measured in decibels, with a decibel being the ratio of one sound to another. One decibel (dB) is the smallest change in sound intensity the human ear can detect. A faint whisper would have an intensity of 20 dB, and a pneumatic drill would be 80 dB. The engine on a modern jetliner, at takeoff thrust, would have a sound intensity of 90 dB when heard by someone standing 150 ft away. A 110 dB noise, by comparison, would sound twice as loud as the jetliner's engine. *Figure 5-7* shows the sound intensity from a variety of different sources.

PITCH AND QUALITY

The term "pitch" is used to describe the frequency of a sound. The outstanding recognizable difference between the tones produced by two different keys on a piano is a difference in pitch. The pitch of a tone is proportional to the number of compressions and rarefactions received per second, which in turn, is determined by the vibration frequency of the sounding source. A good example of frequency is the noise generated by a turbofan engine on a commercial airliner. The high tip speeds of the fan in the front of the engine creates a high frequency sound, and the hot exhaust creates a low frequency sound.

Loudness

When a bell rings, the sound waves spread out in all directions and the sound is heard in all directions. When a bell is struck lightly, the vibrations are of small amplitude and the sound is weak. A stronger blow produces vibrations of greater amplitude in the bell, and the sound is louder. It is evident that the amplitude of the air vibrations is greater when the amplitude of the vibrations of the source is increased. Hence, the loudness of the sound depends on the amplitude of the vibrations of the sound waves. As the distance from the source increases, the energy in each wave spreads out, and the sound becomes weaker.

As the sound wave advances, variations in pressure occur at all points in the transmitting medium. The greater the pressure variations, the more intense the sound wave. The intensity is proportional to the square of the pressure variation regardless of the frequency. Thus, by measuring pressure changes, the intensities of sounds having different frequencies can be compared directly.
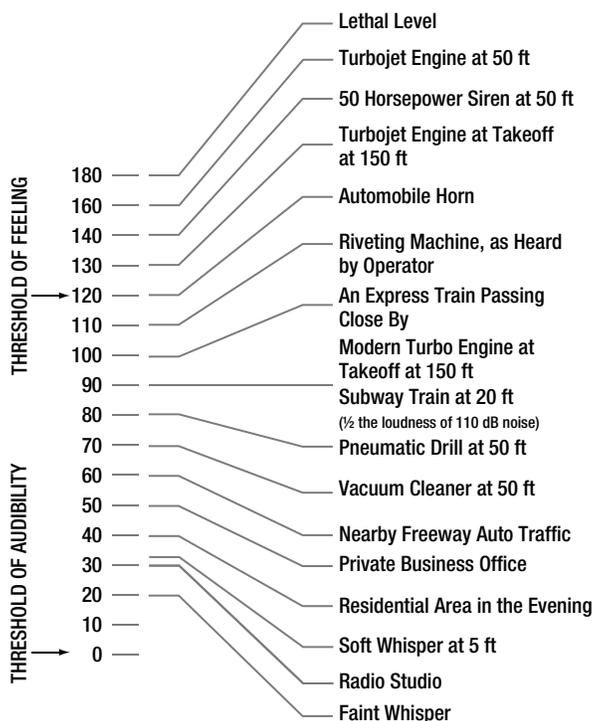
Figure 5-7. Sound intensity from different sources.

Note that if the medium in which the sound wave is propagating has boundaries, the wave will reverse when it hits the boundary and travel back in the direction from which it came. The original and reflected wave can combine to form a standing wave dependent on the distance of the boundary and the frequency and wavelengths of the sound waves.

DOPPLER EFFECT

When sound is coming from a moving object, the object's forward motion adds to the frequency as sensed from the front and takes away from the frequency as sensed from the rear. This change in frequency is known as the Doppler effect, and it explains why the sound from an airplane seems different as it approaches compared to how it sounds as it flies overhead. As it approaches, it becomes both louder and higher pitched. As it flies away, the loudness and pitch both decrease noticeably.

If an airplane is flying at or higher than the speed of sound, the sound energy cannot travel out ahead of the airplane, because the airplane catches up to it the instant it tries to leave. The sound energy being created by the airplane piles up, and attaches itself to the structure of the airplane. As the airplane approaches, a person standing on the ground will not be able to hear it until it gets past their position, because the sound energy is actually trailing behind the airplane. When the sound of the airplane is heard, it will be in the form of what is called a sonic boom.

AIRCRAFT
TECHNICAL
BOOK COMPANY

Question: 5-1

What are the three elements required for the transmission and reception of sound?

Question: 5-2

The ratio of the speed of an aircraft to the speed of sound is called the _____.

Question: 5-3

The amplitude of a sound wave determines the _____ of the tone that is heard.

Question: 5-4

What type of wave is associated with the production of music?

Question: 5-5

If two mechanical waves of equal amplitude and frequency meet, what will occur?

Question: 5-6

Name 5 types of waves which can travel without the need of a medium.

ANSWERS

Answer: 5-1

A source, a medium for carrying the sound, and a detector.

Answer: 5-2

mach number.

Answer: 5-3

loudness.

Answer: 5-4

Longitudinal waves.

Answer: 5-5

The waves will cancel each other out.

Answer: 5-6

radio waves, microwaves; light waves, X-rays, gamma waves

AMC	/	Acceptable Means of Compliance
BHP	/	Bore Horsepower
BTU	/	British Thermal Unit
CHT	/	Cylinder Head Temperature
CG	/	Center of Gravity
CM³	/	Cubic Centimeter
CPU	/	Central Processing Unit
dB	/	Decibel
EF	/	Effort Arm
EGT	/	Exhaust Gas Temperature
F	/	Farenheit
FPS	/	Feet Per Second
FPS/S	/	Feet Per Second per Second
FR	/	Resistance Arm
ft³	/	Cubic Foot
ft-lbs	/	Foot-pounds
ft-lbs/s	/	Foot-pounds Per Second
G/CM³	/	Grams Per Cubic Centimeter
Gs	/	Force of Gravity
GM	/	Guidance Material
HP	/	Horsepower
Hz	/	Hertz
ICAO	/	International Civil Aviation Organization
IHP	/	Indicated Horsepower
KE	/	Kinetic Energy
LB/FT³	/	Pounds Per Cubic Foot
LED	/	Light Emitting Diodes
MPH	/	Miles Per Hour
PE	/	Potential Energy
PSI	/	Pounds Per Square Inch
OAT	/	Outside Air Temperature
R	/	Resistance
PV	/	Pressure-volume
PC	/	Physical Contact

# #

A

B

C

D

E

F

G

H

I

V

W