A&P TEST READY

VOLUME 1

THE STUDY GUIDE

GENERAL

Electricity · Materials · Regulations · Maintenance Practices



FAA Aviation Mechanic Written Test

Complete ACS knowledge coverage · Worked examples · Glossary & Index

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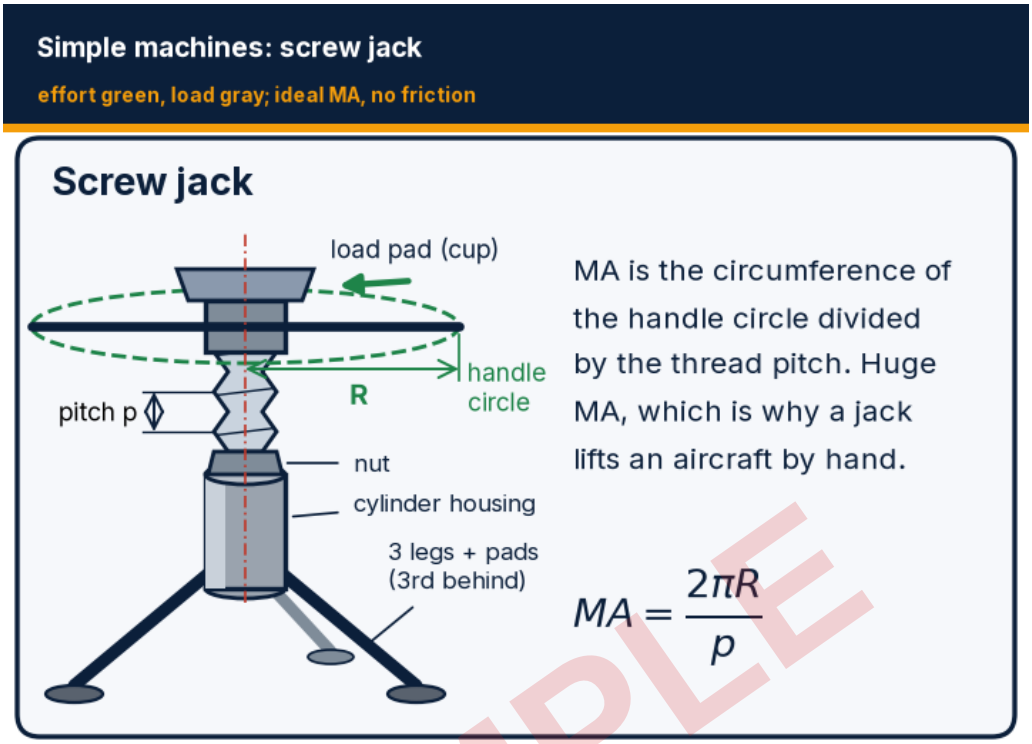


Figure 2-6 (continued).

- **Inclined plane:** MA = length of the slope ÷ height.
- **Wheel and axle:** MA = wheel radius ÷ axle radius. A screwdriver handle and a control wheel are examples.
- **Gears:** the speed ratio equals the ratio of the numbers of teeth. A small gear driving a large one reduces speed and *increases* torque. A propeller reduction gear does exactly this.
- **Screw:** a thread is an inclined plane wrapped around a cylinder. A screw jack gives a very large MA.

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WORKED EXAMPLE

Worked Example 2-4. A 20-tooth drive gear turns a 60-tooth driven gear at 3,000 rpm input. What is the output speed?

$$\text{Ratio} = \frac{60}{20} = 3:1$$

$$\text{Output} = \frac{3{,}000}{3} = 1{,}000 \text{ rpm}$$

The output is **1,000 rpm**, with three times the torque (less friction losses).

Stress and **strain** are introduced with materials in Chapter 6.

2.4 Heat, Temperature, Pressure and the Gas Laws

Heat and temperature

Heat is energy that flows from a hotter body to a cooler one. **Temperature** measures how hot something is. Heat is measured in British thermal units (BTU); one BTU raises 1 lb of water 1 °F. *Specific heat* is the heat needed to raise a unit mass of a substance one degree; water's is high (1.0), which is why it is a good coolant.

Heat moves three ways:

- **Conduction:** through a material by direct contact (a cylinder fin conducting heat away from the barrel).
- **Convection:** by the movement of a fluid (air flowing past the fins; warm air rising in a hangar).
- **Radiation:** by electromagnetic waves, with no medium needed (sunlight heating a dark wing).

Metals expand when heated. *Thermal expansion* is why exhaust parts have slip joints, why a cold aluminum tank reads less fuel volume, and why a valve-clearance check must be done at the specified engine temperature.

Four temperature scales are used (Figure 2-7). Fahrenheit and Celsius are relative scales; Kelvin and Rankine are **absolute temperature** scales that start at **absolute zero**, the point at which molecular motion would stop.

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Four temperature scales
Drawn to one linear scale: absolute zero is far below freezing

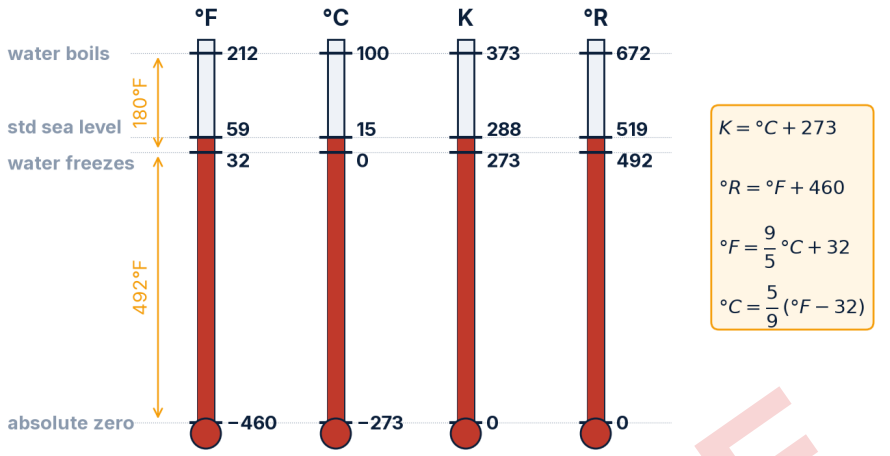


Figure 2-7. The four temperature scales and their conversions.

- °F = ($\frac{9}{5}$ × °C) + 32
- °C = $\frac{5}{9}$ × (°F − 32)
- K = °C + 273
- °R = °F + 460

Pressure

Pressure is force per unit area, usually in pounds per square inch (psi). Standard sea-level atmospheric pressure is 14.69 psi, 29.92 in Hg, or 1013.2 hPa (millibars).

- **Gauge pressure (psig)** is measured above atmospheric pressure. Tire and hydraulic gauges read gauge pressure.
- **Absolute pressure (psia)** is measured from a perfect vacuum: psia = psig + atmospheric pressure.
- **Differential pressure** is the difference between two pressures, such as cabin pressure and outside air pressure.

A manifold pressure gauge reads absolute pressure in inches of mercury; with the engine stopped it shows the local atmospheric pressure.

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The gas laws

Gases follow simple laws as long as you use **absolute** pressure and **absolute** temperature (Figure 2-8).

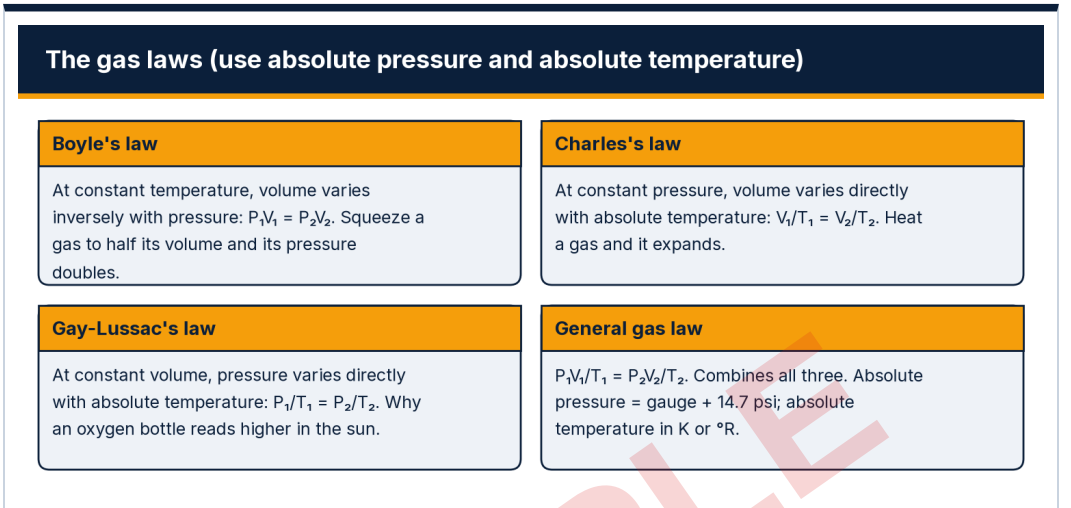


Figure 2-8. The gas laws. Always convert to absolute pressure and absolute temperature first.

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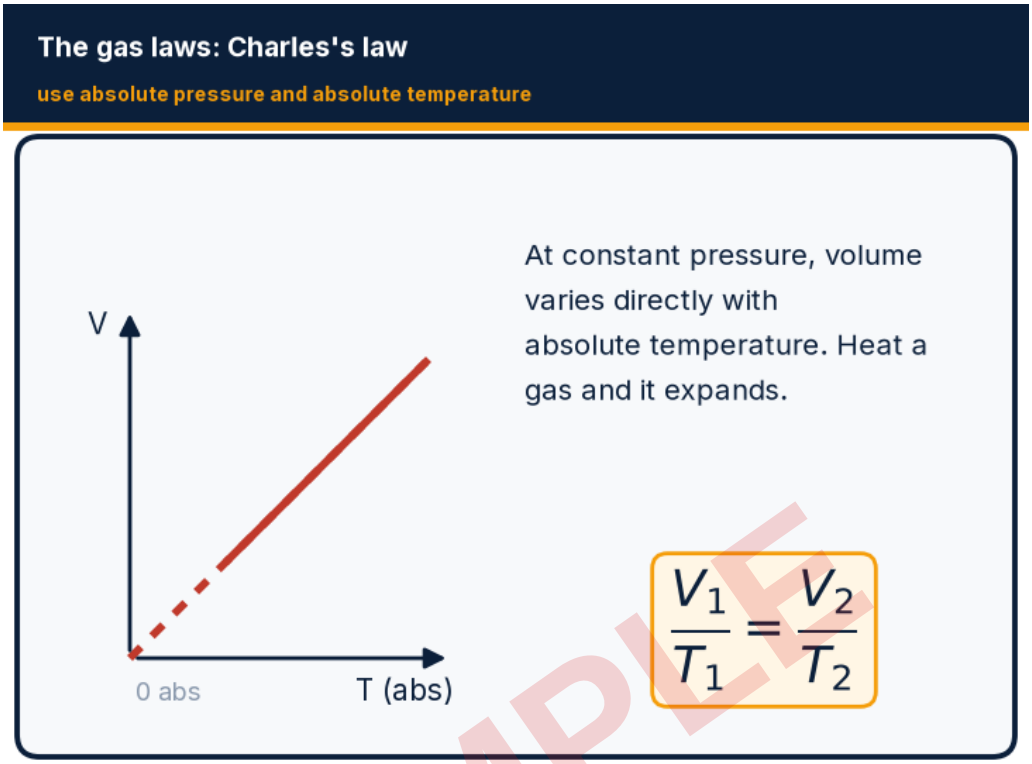


Figure 2-8 (continued).

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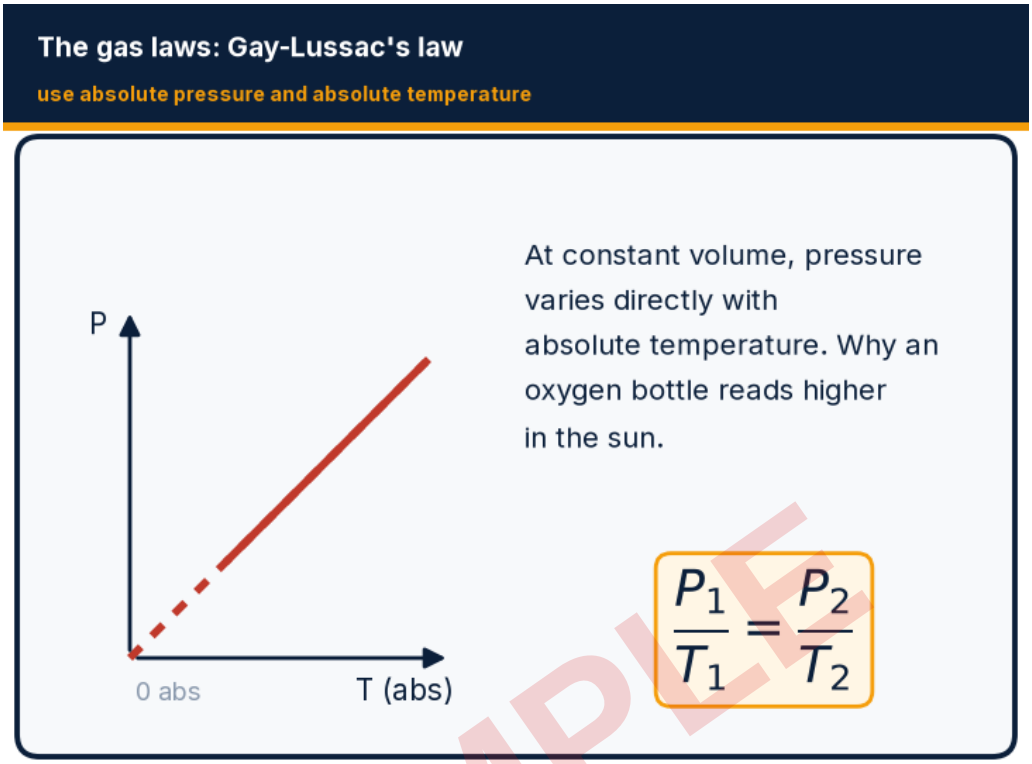


Figure 2-8 (continued).

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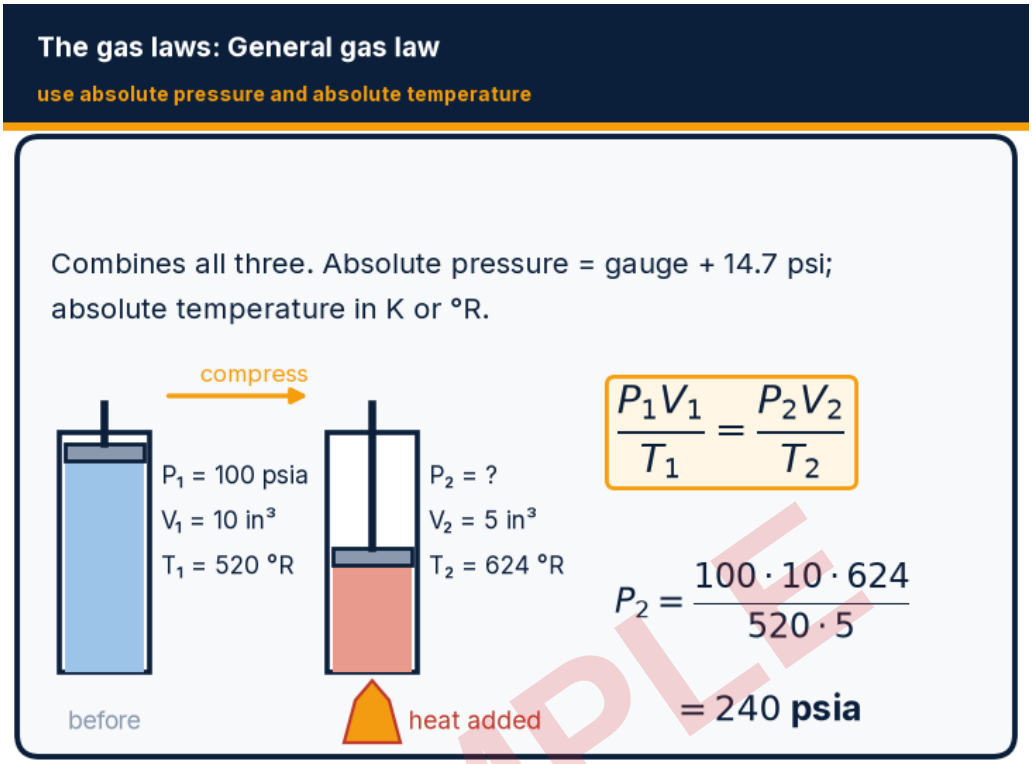


Figure 2-8 (continued).

SAMPLE

- **Boyle's law**: at constant temperature, volume varies inversely with pressure: $P_1V_1 = P_2V_2$.
- **Charles's law**: at constant pressure, volume varies directly with absolute temperature: $\frac{V_1}{T_1} = \frac{V_2}{T_2}$. At constant volume, pressure varies directly with absolute temperature (Gay-Lussac's law).
- **General gas law:** $\frac{P_1V_1}{T_1} = \frac{P_2V_2}{T_2}$.

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WORKED EXAMPLE

Worked Example 2-5. A cylinder holds 2 ft³ of air at 50 psig. If the air is compressed to 1 ft³ at the same temperature, what is the new gauge pressure?

Convert to absolute pressure first, then apply Boyle's law:

$$P_1 = 50 + 14.7 = 64.7 \text{ psia}$$

$$P_2 = \frac{P_1 \times V_1}{V_2} = \frac{64.7 \times 2}{1} = 129.4 \text{ psia}$$

$$\text{Gauge} = 129.4 - 14.7 = 114.7 \text{ psig}$$

The new pressure is **114.7 psig**. (Simply doubling 50 psig to 100 psig is the classic wrong answer.)

WORKED EXAMPLE

Worked Example 2-6. A sealed oxygen bottle at 1,800 psig and 70 °F heats to 120 °F in the sun. What is the new pressure?

P_1 = 1,814.7 psia; T_1 = 530 °R; T_2 = 580 °R.

$$P_2 = \frac{P_1 \times T_2}{T_1} = \frac{1{,}814.7 \times 580}{530}$$

$$= 1{,}985.9 \text{ psia}$$

$$\approx 1{,}971 \text{ psig}$$

The new pressure is **about 1,971 psig**. This is why oxygen bottles are filled to temperature-corrected pressures.

SAMPLE

Temperature, density, weight and volume

For a given mass of gas, raising its temperature at constant pressure increases its volume and so lowers its density. A cubic foot of hot air weighs less than a cubic foot of cold air. Liquids also expand when heated: a full fuel tank filled with cold fuel can overflow through the vent as the fuel warms, and fuel is sold by

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volume but burned by weight. For fuel, weight = volume × density; avgas is 6 lb/gal at standard temperature, but slightly less when warm.

2.5 Fluid Mechanics: Pascal's Law

Pascal's law states that pressure applied to an enclosed fluid is transmitted equally and undiminished in all directions, and acts at right angles to the container walls. This is how hydraulic brakes, jacks and actuators work (Figure 2-9).

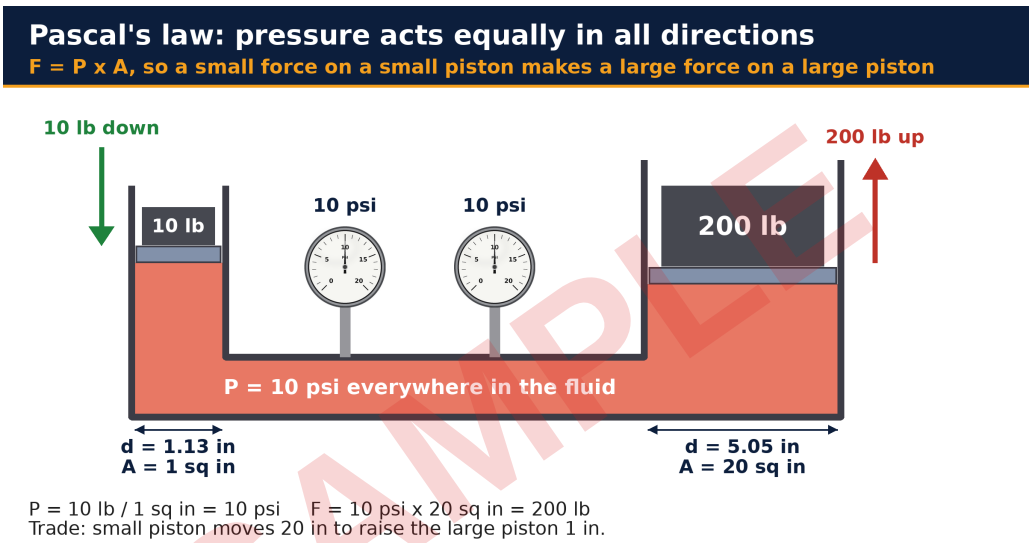


Figure 2-9. Pascal's law. A small force on a small piston creates pressure that a larger piston turns into a larger force; the trade is distance.

The working relationship is:

$$F = P \times A \qquad P = \frac{F}{A} \qquad A = \frac{F}{P}$$

SAMPLE

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WORKED EXAMPLE

Worked Example 2-7. A hydraulic system operates at 3,000 psi. What force does an actuator with a 2-in-diameter piston produce?

$$A = 0.7854 \times 2^2 = 3.1416 \text{ in}^2$$

$$F = P \times A = 3{,}000 \times 3.1416 = 9{,}425 \text{ lb}$$

The actuator produces **9,425 lb**.

WORKED EXAMPLE

Worked Example 2-8. In Figure 2-9, a 10-lb force acts on a 1-in² piston. What force does the 30-in² piston exert, and how far does it move if the small piston moves 6 in?

$$P = \frac{10}{1} = 10 \text{ psi}$$

$$F = 10 \times 30 = 300 \text{ lb}$$

$$\text{Volume moved} = 1 \times 6 = 6 \text{ in}^3$$

$$\text{Large piston travel} = \frac{6}{30} = 0.2 \text{ in}$$

The large piston exerts **300 lb** and moves **0.2 in**. You gain force and lose distance.

SAMPLE

In a double-acting actuator, the rod side has less effective area than the cap side (the rod takes up area), so at the same pressure it produces less force on retraction.

Hydrostatic pressure depends only on the height of a liquid column and its density, not on the container's shape: each foot of water exerts 0.433 psi. *Buoyancy* (Archimedes' principle): a body in a fluid is pushed up by a force equal to the weight of the fluid it displaces.

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2.6 The Standard Atmosphere and Density Altitude

The atmosphere is about 78 % nitrogen and 21 % oxygen, with traces of argon, carbon dioxide and water vapor. Pressure and density fall as altitude increases. Because real weather varies, engineers use the **International Standard Atmosphere** (ISA) as a common reference for performance and instrument calibration (Figure 2-10).

The ICAO standard atmosphere (selected values)
Temperature lapse about 2 °C (3.5 °F) per 1,000 ft up to the tropopause

Altitude (ft)	Temp (°F / °C)	Pressure (inHg)	Pressure (psi)	Density ratio
Sea level	59 / 15	29.92	14.69	1.000
5,000	41.2 / 5.1	24.90	12.23	0.862
10,000	23.3 / −4.8	20.58	10.11	0.738
18,000	−5.1 / −20.6	14.94	7.34	0.563
20,000	−12.3 / −24.6	13.75	6.75	0.533
36,089	−69.7 / −56.5	6.68	3.28	0.297

Figure 2-10. Selected values from the ICAO standard atmosphere.

SAMPLE

Standard sea-level conditions are 59 °F (15 °C), 29.92 in Hg (14.69 psi), and a density of 0.002377 slug/ft³. Temperature falls about 2 °C (3.5 °F) per 1,000 ft up to the tropopause, at about 36,000 ft, above which it stays near −56.5 °C.

- **Pressure altitude** is the altitude read on an altimeter set to 29.92 in Hg.
- **Density altitude** is pressure altitude corrected for non-standard temperature. It is the altitude the aircraft “feels.”

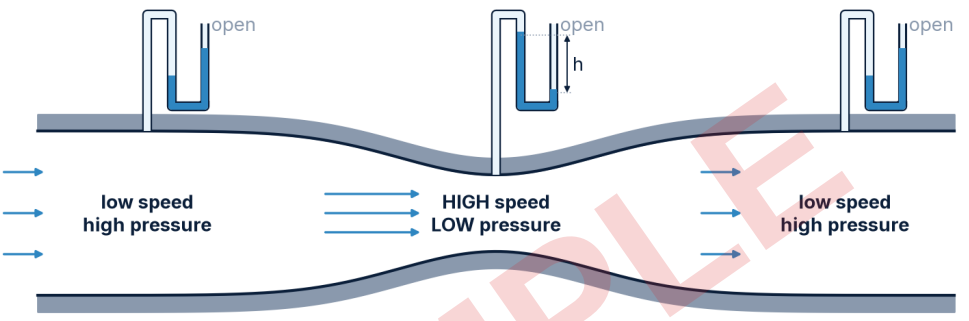
Three factors raise density altitude (lower air density): **high altitude (low pressure), high temperature and high humidity**. Water vapor is lighter than the dry air it displaces, so humid air is *less* dense than dry air at the same temperature and pressure. High density altitude reduces engine power, propeller thrust and wing lift, so takeoff runs get longer and climb rates fall.

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2.7 Bernoulli’s Principle and the Theory of Flight

Bernoulli’s principle states that when the velocity of a fluid increases, its static pressure decreases, provided the total energy stays constant. In a **venturi**, air speeds up through the narrow throat and its pressure drops (Figure 2-11). Carburetors, venturi vacuum sources and the airflow over a wing all use this principle.

Bernoulli's principle in a venturi



Total energy stays constant: when velocity rises, static pressure falls.
Carburetors, venturi vacuum sources and wings use this.

Figure 2-11. Bernoulli’s principle. At the throat of a venturi, velocity is highest and static pressure is lowest.

SAMPLE

Reading the venturi manometers

U-tube manometer

One leg goes to the tap, one is open to the atmosphere.

Inlet and outlet

Pressure is above atmospheric: the tap leg is pushed down.

Throat

Pressure is lowest: the tap leg pulls the fluid up by h.

Figure 2-11 (continued).

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The airfoil

An **airfoil** is a surface shaped to produce lift as air flows past it. Key terms are shown in Figure 2-12.

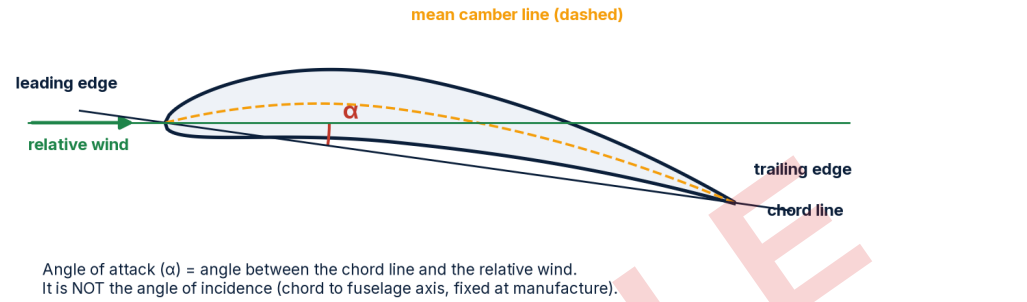


Figure 2-12. Airfoil terms. Angle of attack is measured between the chord line and the relative wind.

- The **chord line** is a straight line from the leading edge to the trailing edge.
- **Camber** is the curvature of the airfoil's mean line.
- The **relative wind** is the airflow relative to the airfoil, parallel to and opposite the flight path.
- **Angle of attack** (AOA) is the angle between the chord line and the relative wind.
- **Angle of incidence** is the fixed angle between the chord line and the aircraft's longitudinal axis. It is set during manufacture and checked when rigging.

Air flowing over the curved upper surface speeds up and its pressure drops; Newton's third law adds lift as the wing deflects air downward. Lift increases with angle of attack, airspeed (with the square of velocity), air density and wing area. At the **critical angle of attack** (about 15–20° for most airfoils) the airflow separates from the upper surface and the wing **stalls**. A stall is caused by exceeding the critical angle of attack, not by a particular airspeed.

SAMPLE

The four forces

In straight-and-level unaccelerated flight, **lift equals weight and thrust equals drag** (Figure 2-13).



Figure 2-13. The four forces of flight.

Drag comes in two kinds:

- **Parasite drag** comes from the airframe moving through the air: form drag, skin friction and interference drag. It increases with speed.
- **Induced drag** is a by-product of lift, caused by wingtip vortices as high-pressure air under the wing spills toward the low-pressure air above it. It is greatest at low speed and high angle of attack.

Stability and the three axes

An aircraft moves about three axes, each passing through the center of gravity (Figure 2-14).

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Three axes, three primary controls

TOP VIEW — rudder yaws the airplane about the vertical axis

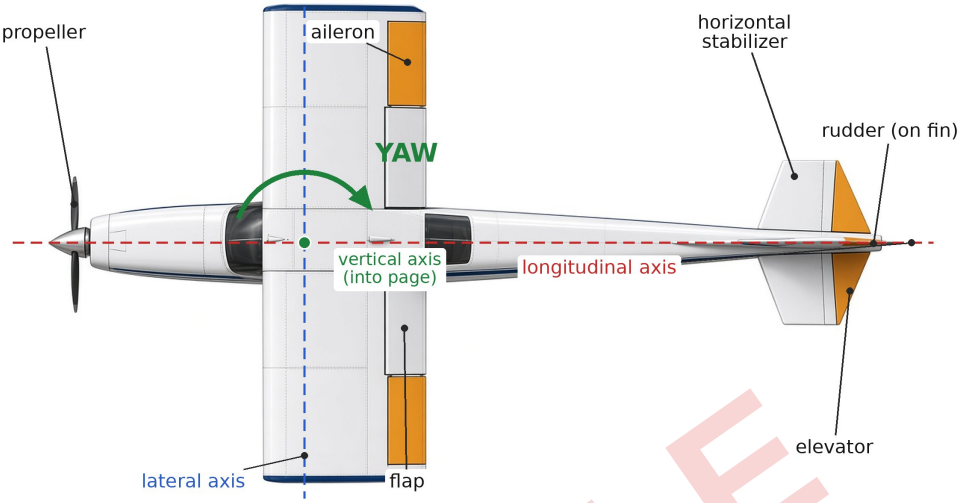


Figure 2-14. The three axes of rotation and the controls that move the aircraft about them.

Three axes, three primary controls (continued)

FRONT VIEW — ailerons roll the airplane about the longitudinal axis

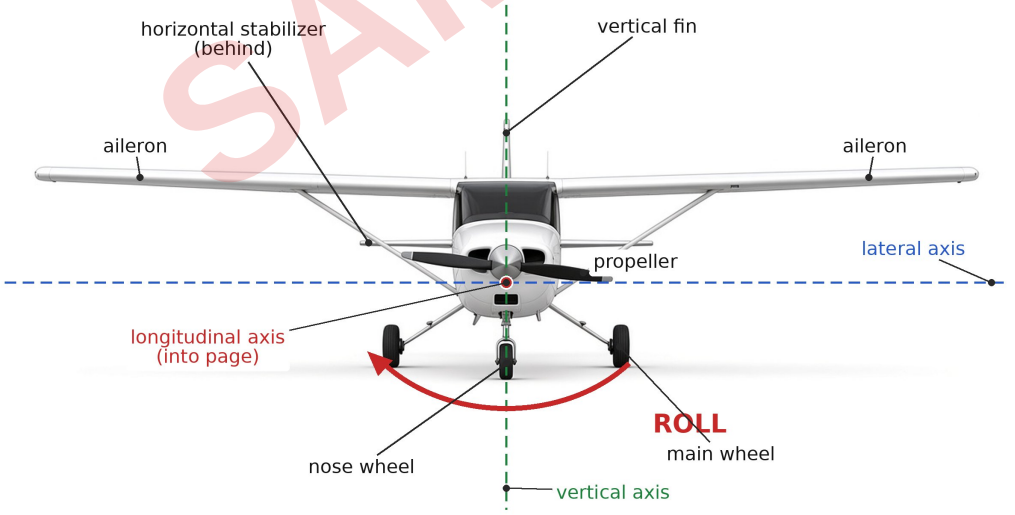


Figure 2-14 (continued).

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Three axes, three primary controls (continued)

SIDE VIEW — elevator pitches the airplane about the lateral axis

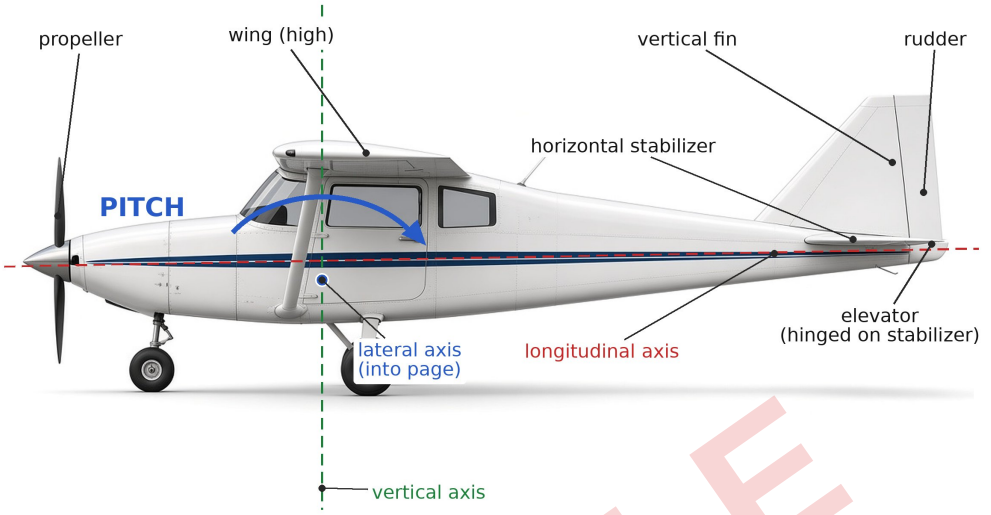


Figure 2-14 (continued).

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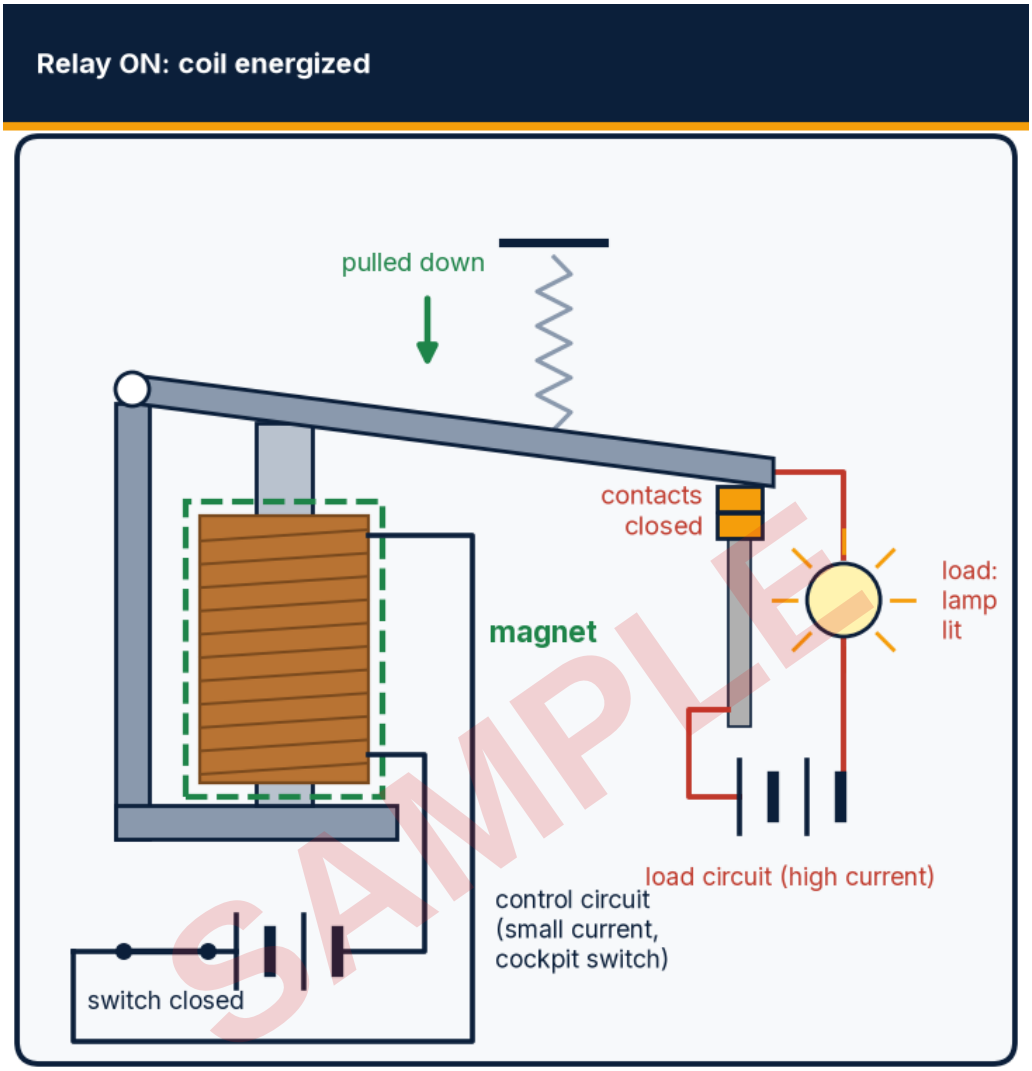


Figure 3-11 (continued).

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How a relay works

1. Coil on

A small current energizes the coil; it becomes a magnet.

2. Contacts close

The armature is pulled down and the contacts close the separate, high-current load circuit.

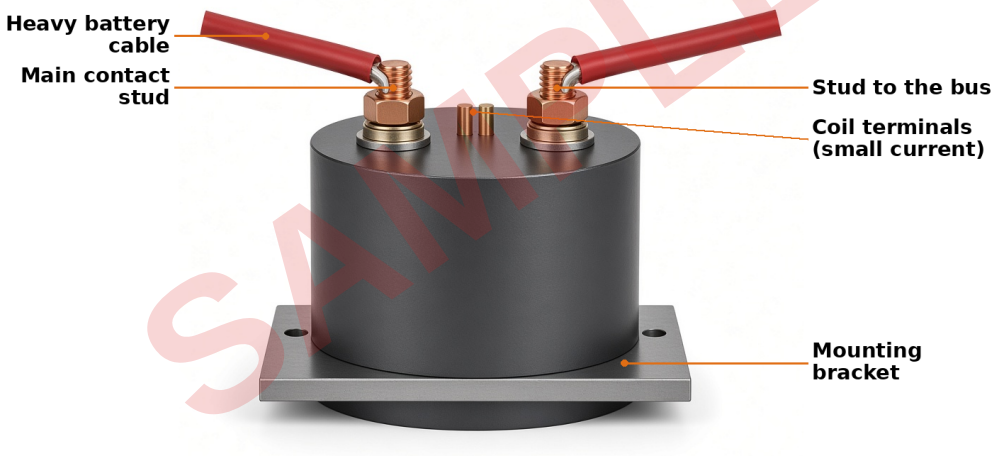
3. Coil off

The spring opens the contacts.

Solenoid

A relay with a movable plunger core, used for heavy loads (starter, master).

Figure 3-11 (continued).



Real-part view: battery/starter relay

Protective devices

Circuit protection exists to protect the **wiring**. It must open before the wire overheats.

- A **fuse** melts and opens the circuit; it must be replaced. For night VFR and IFR flight, 14 CFR 91.205(c)(6) requires one spare set of fuses, or three spare fuses of each kind required, accessible to the pilot in flight.

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- A **circuit breaker** opens on overcurrent and can be reset. Aircraft breakers are *trip-free*: they cannot be held closed against a fault.
- A current limiter is a slow-blow copper fuse that tolerates large current for a short time; it is used in heavy power circuits.
- Thermal protectors (thermal switches) open a motor circuit if the motor overheats.

Cartridge fuse

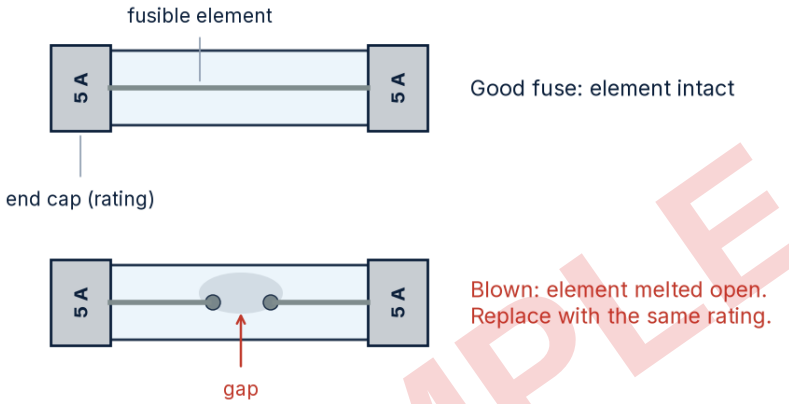


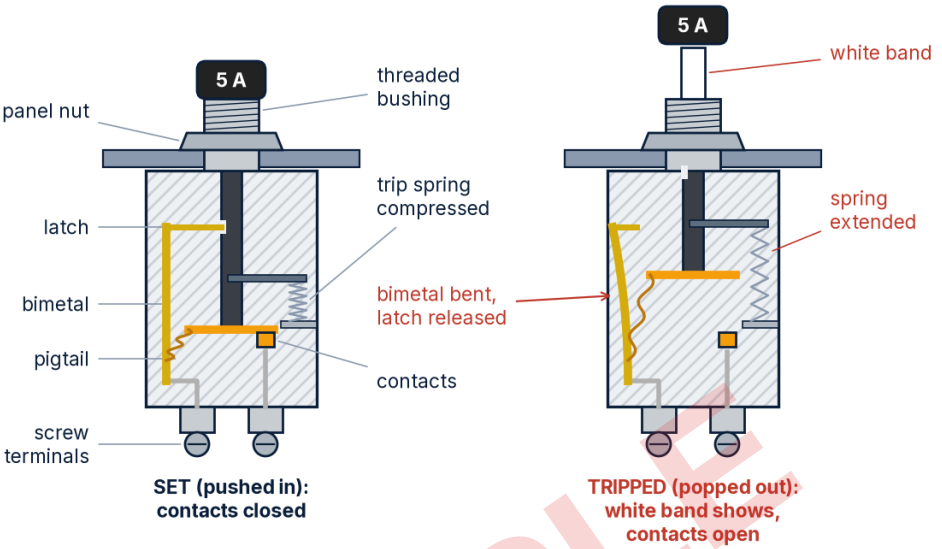
Figure 3-12. Fuse and circuit breaker. A blown cartridge fuse has a melted element and must be replaced with one of the same rating. A tripped push-pull breaker pops out to show a white band; it is reset by pushing it in once the fault is found.

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Push-pull circuit breaker

Thermal element opens on overcurrent; push to reset. Trip-free: it cannot be held closed against a fault.



Load-current path: left terminal → bimetal → pigtail → contact bar → fixed contact → right terminal. Overcurrent heats the bimetal; it bends off the latch and the trip spring drives the button out.

Figure 3-12 (continued).



Real-part view: push-pull breakers and a blown fuse

Rule. Do not reset a tripped breaker repeatedly. Find the fault first. Never install a breaker or fuse rated higher than the wire it protects.

SAMPLE

Voltage regulation

A generator or alternator output rises with speed and falls with load. A **voltage regulator** holds bus voltage constant (about 14 V on a 12-V system, 28 V on a 24-V system) by controlling **field current**. Older units used vibrating contacts and carbon piles; modern units are solid-state, often built around a Zener diode reference (Section 3.8). An overvoltage relay or crowbar circuit takes the generator off line if regulation fails.

3.11 Digital Electronics and Electrostatic Discharge

Binary numbers

Digital systems use the **binary** (base-2) number system, which has only two digits, 0 and 1. Each place value doubles: 1, 2, 4, 8, 16, 32 ...

WORKED EXAMPLE

Worked Example 3-12. Binary conversion. Convert 1011_2 to decimal:

$$(1 \times 8) + (0 \times 4) + (1 \times 2) + (1 \times 1) = 8 + 0 + 2 + 1$$
$$= 11$$

Convert 25 to binary (places 16-8-4-2-1):

$$25 = 16 + 8 + 1$$
$$= 11001_2$$

SAMPLE

Logic gates

A **logic gate** produces an output based on its inputs:

Table 3-5. Logic gate truth summary.

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Gate	Output is 1 when…
AND	All inputs are 1
OR	Any input is 1
NOT (inverter)	Input is 0 (it reverses the input)
NAND	Not all inputs are 1 (AND followed by NOT)
NOR	No input is 1 (OR followed by NOT)
XOR (exclusive OR)	Inputs differ

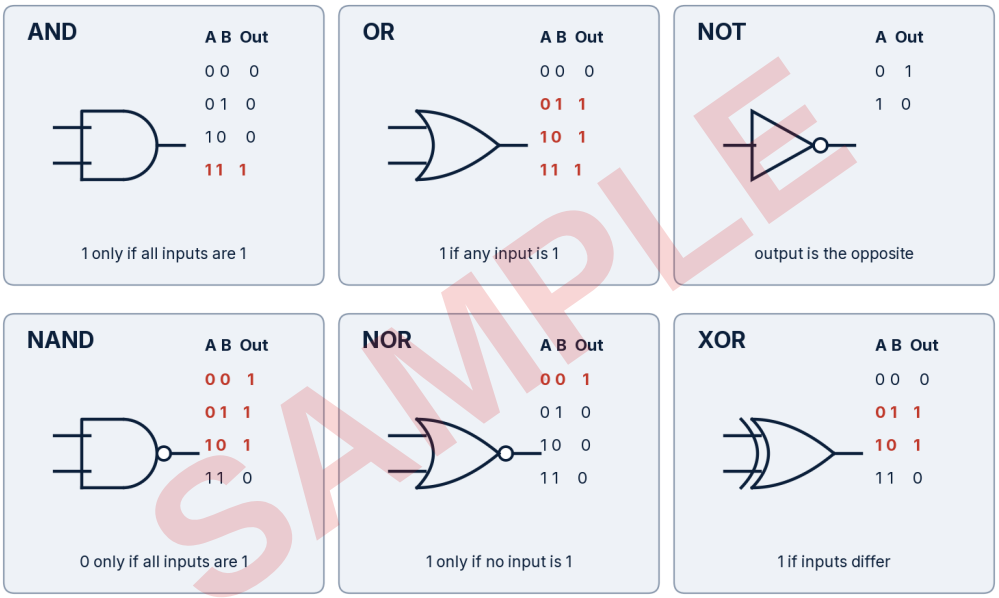


Figure 3-13. Logic gate symbols and truth tables. A small circle (bubble) on an output means the output is inverted: NAND is AND followed by NOT, and NOR is OR followed by NOT. Rows that give an output of 1 are shown in red.

A **flip-flop** is a circuit of gates with two stable states, so it stores one bit; it is the building block of registers and counters. An integrated circuit (IC) packs many transistors, gates and flip-flops on one silicon chip.

Memory

- **RAM** (random-access memory) is read/write and **volatile**: contents are lost when power is removed.

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- **ROM** (read-only memory) is programmed permanently and retains data without power.
- **NVRAM** (non-volatile RAM) and flash memory can be rewritten but keep their data without power; avionics use them for configuration and fault logs.

Electrostatic discharge

Electrostatic discharge (ESD) can destroy semiconductor devices at voltages far too low to feel. Components marked as ESD-sensitive must be handled with a grounded wrist strap at a grounded workstation, kept in conductive or static-shielding bags, and never touched by their pins.

Electrical circuit drawings

Electrical systems are documented on schematic diagrams (which show function with standard symbols), wiring diagrams (which show actual wire numbers, connectors and routing) and block diagrams (which show major units only). Aircraft drawings and symbols are covered in Chapter 4.

SAMPLE

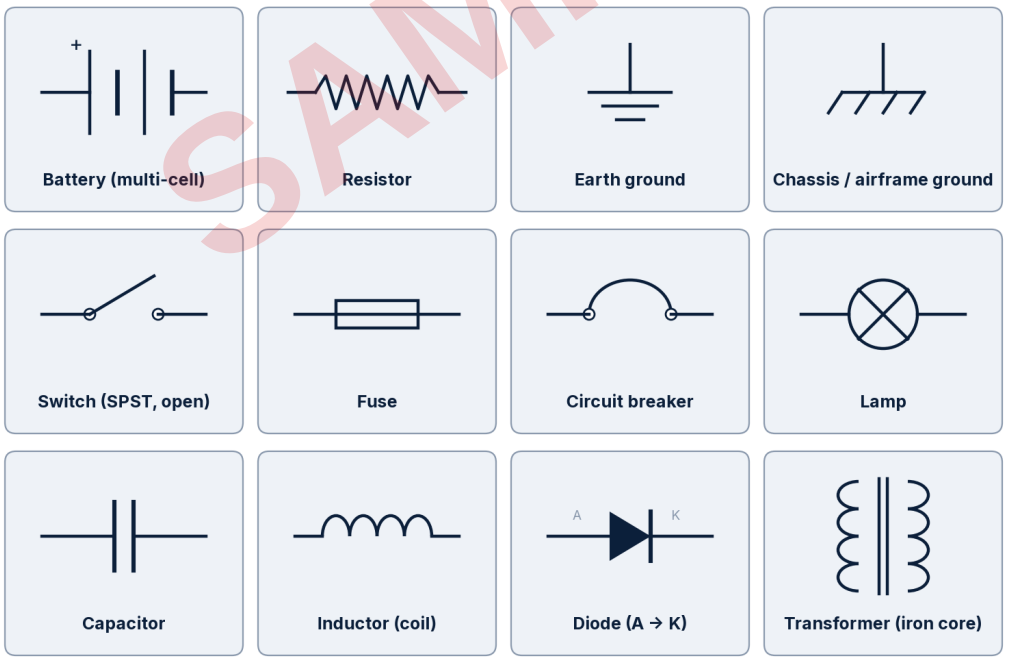


Figure 3-14. Common schematic symbols used in aircraft electrical diagrams (part 1). On the battery symbol, the long plate is positive.

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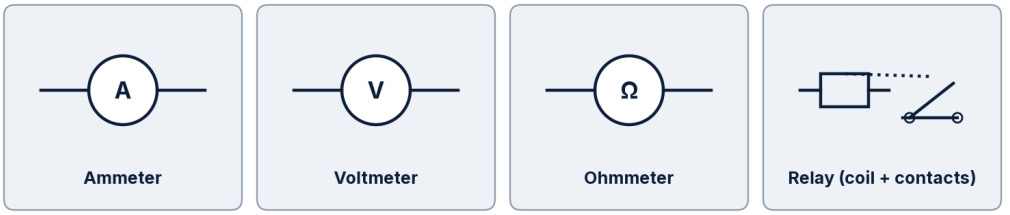


Figure 3-15. Common schematic symbols (part 2): meters and a relay. The dotted line shows the coil mechanically operating the contacts.

3.12 Aircraft Batteries



Figure 3-16. Servicing a vented lead-acid battery. A hydrometer reads the specific gravity of the electrolyte in each cell; goggles and gloves are worn because the electrolyte is sulfuric acid.

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