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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Chapter 3. Fundamentals of Electricity and Electronics

3.2 Electrical Quantities and Units

Four quantities describe every DC circuit. Learn the symbol and unit for each; the test uses both.

Table 3-1. Basic electrical quantities.

Quantity	Symbol	Unit	Unit symbol	Measured with
Electromotive force (voltage)	E (or V)	volt	V	Voltmeter
Current	I	ampere	A	Ammeter
Resistance	R	ohm	Ω	Ohmmeter
Power	P	watt	W	Wattmeter (or calculated)

SAMPLE

Charge and current

The unit of electric charge is the **coulomb** (C), equal to about 6.28×10^{18} electrons. **Current** is the rate at which charge moves past a point. One **ampere** is a flow of one coulomb per second.

Electromotive force

Electromotive force (emf), or voltage, is the electrical pressure that pushes electrons through a circuit. It is a *difference of potential* between two points. A battery creates emf chemically; a generator creates it magnetically. Without a difference of potential, no current flows, no matter how good the conductor. One **volt** is the emf that pushes one ampere through one ohm.

A water analogy helps: voltage is like pressure in a pipe, current is like the flow rate, and resistance is like a restriction in the pipe.

Resistance

Resistance is the opposition to current flow. It turns electrical energy into heat. The resistance of a conductor depends on four factors:

1. **Material.** Each material has its own **resistivity**. Copper has lower resistivity than aluminum.
2. **Length.** Resistance increases in direct proportion to length.
3. **Cross-sectional area.** Resistance decreases as area increases. Doubling the diameter quadruples the area, so it cuts resistance to one-quarter.
4. **Temperature.** For most metals, resistance rises as temperature rises (a *positive temperature coefficient*). Carbon and semiconductors have a negative coefficient.

SAMPLE

These four factors are why aircraft wire size is chosen from wire charts[1] by current, length and allowable voltage drop. In the American Wire Gauge (AWG) system, *larger gauge numbers mean smaller wire*.

Resistors and the color code

A **resistor** is a component made to have a specific resistance. Carbon-composition and film resistors are marked with color bands:

Table 3-2. Resistor color code: digit and multiplier values.

Color	Digit	Multiplier	Color	Digit	Multiplier
Black	0	×1	Green	5	×100,000
Brown	1	×10	Blue	6	×1,000,000
Red	2	×100	Violet	7	—
Orange	3	×1,000	Gray	8	—
Yellow	4	×10,000	White	9	—

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In the multiplier band, gold = ×0.1 and silver = ×0.01. In the tolerance band, gold = ±5 %, silver = ±10 % and no band = ±20 %.

1 AC 43.13-1B, Chapter 11

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Color	1st digit	2nd digit	Multiplier	Tolerance
Black	0	0	×1	
Brown	1	1	×10	
Red	2	2	×100	
Orange	3	3	×1 k	
Yellow	4	4	×10 k	
Green	5	5	×100 k	
Blue	6	6	×1 M	
Violet	7	7	×10 M	
Gray	8	8		
White	9	9		
Gold			×0.1	±5 %
Silver			×0.01	±10 %

No band: ±20 %

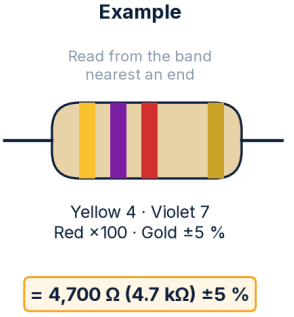


Figure 3-3. The resistor color code. The first two bands are digits, the third is the multiplier and the fourth is the tolerance. Memory aid for the order black to white (0–9): "Better Be Right Or Your Great Big Venture Goes West."

SAMPLE

WORKED EXAMPLE

Worked Example 3-1. Reading a resistor. Bands are yellow, violet, red, gold.

First digit 4, second digit 7, multiplier ×100: 47 × 100 = **4,700 Ω (4.7 kΩ), ±5 %.** The actual value may be anywhere from 4,465 Ω to 4,935 Ω.

3.3 Ohm's Law and Electrical Power

Ohm's law

Ohm's law states that the current in a circuit is directly proportional to the applied voltage and inversely proportional to the resistance:

$$I = \frac{E}{R} \qquad E = I \times R \qquad R = \frac{E}{I}$$

Figure 3-4 shows the simplest possible circuit: a source (E), a load (R), and an ammeter in series that reads the current (I).

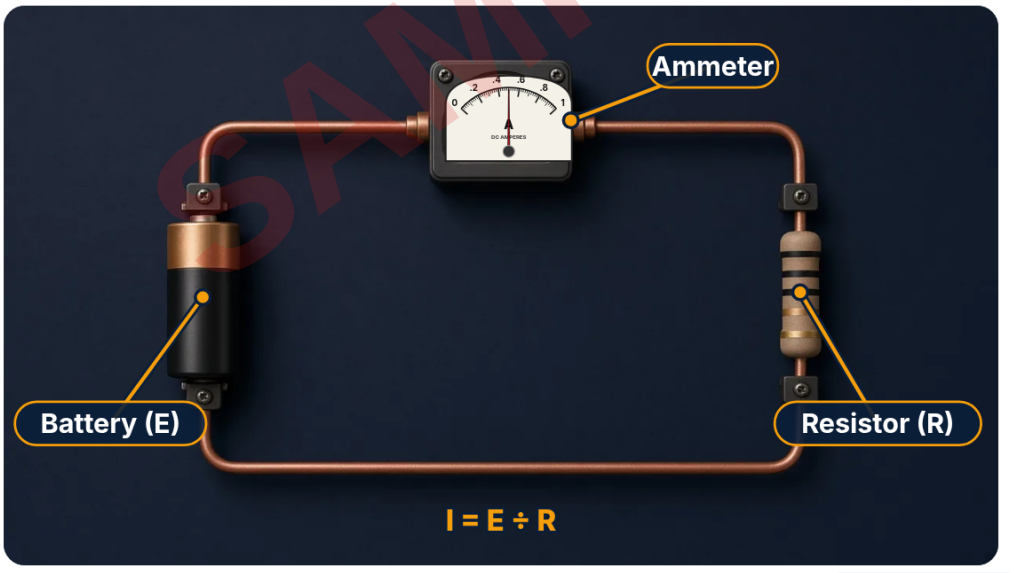


Figure 3-4. A basic series circuit for Ohm's law. The battery supplies emf (E), the resistor is the load (R), and the ammeter, connected in series, reads the current (I). Raise E and the needle rises; raise R and it falls.

SAMPLE

A useful memory aid is the Ohm's law triangle: E on top, I and R on the bottom. Cover the quantity you want; the remaining two show the operation (side by side means multiply, one above the other means divide).

How the triangle helps: you only have to remember one picture instead of three equations, and it tells you whether to multiply or divide. Figure 3-5 walks through all three cases using the same circuit (28 V, 14 Ω, 2 A), so you can check that each version gives a consistent answer. A good habit on the test is to write the triangle in the margin first, cover the unknown with a fingertip, and then substitute numbers with their units.

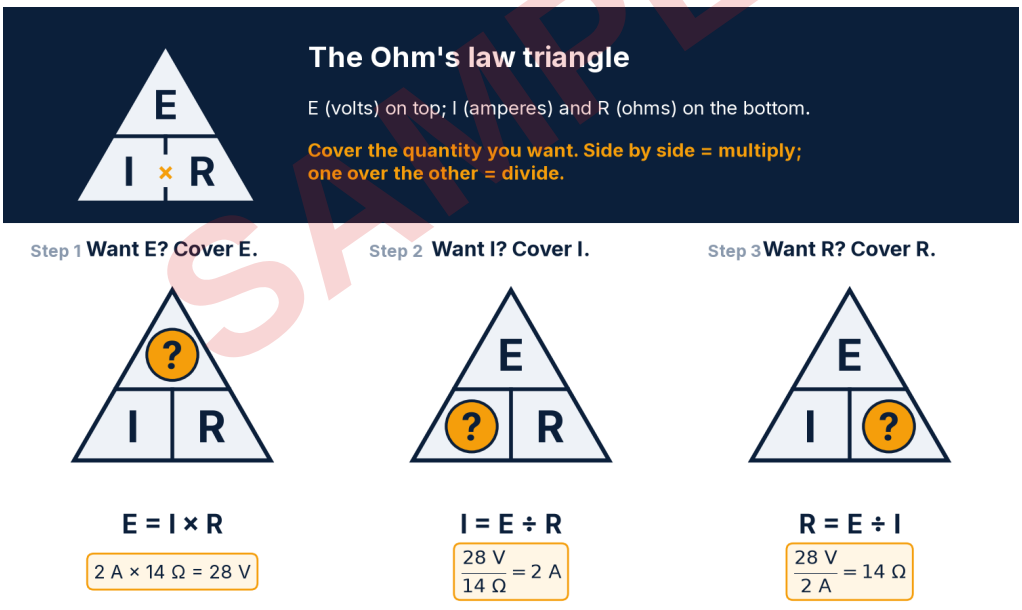


Figure 3-5. The Ohm's law triangle and the 'cover the unknown' method. Step 1: cover E and I sits beside R, so E = I × R. Step 2: cover I and E sits over R, so I = E ÷ R. Step 3: cover R and E sits over I, so R = E ÷ I. Each step is checked with the same 28-V, 14-Ω, 2-A circuit.

SAMPLE

WORKED EXAMPLE

Worked Example 3-2. Finding current. A 28-volt circuit has a total resistance of 7 Ω. What current flows?

$$I = \frac{E}{R} = \frac{28}{7} = 4 \text{ A}$$

The current is **4 A**.

WORKED EXAMPLE

Worked Example 3-3. Finding resistance. A 14-volt landing light draws 6 A. What is its hot-filament resistance?

$$R = \frac{E}{I} = \frac{14}{6} = 2.33\ \Omega$$

The hot resistance is **2.33 Ω**. (Measured cold with an ohmmeter, the filament reads much lower, because tungsten resistance rises sharply with temperature.)

SAMPLE

Power and energy

Power is the rate of doing work. In electrical terms, one **watt** is the power used when one ampere flows under one volt. Combining $P = I \times E$ with Ohm's law gives three forms:

$$P = I \times E \qquad P = I^2 \times R \qquad P = \frac{E^2}{R}$$

Mechanical and electrical power convert at **746 W = 1 horsepower**. Energy is power multiplied by time and is commonly expressed in watt-hours; battery capacity is expressed in ampere-hours (Section 3.12).

The same cover-the-unknown trick works for power. Put P on top and I and E on the bottom (Figure 3-6): cover P and you get I × E; cover I and you get $\frac{P}{E}$; cover E and you get $\frac{P}{I}$. The power wheel combines this triangle with Ohm's law, so any of the four quantities can be found from any two others.

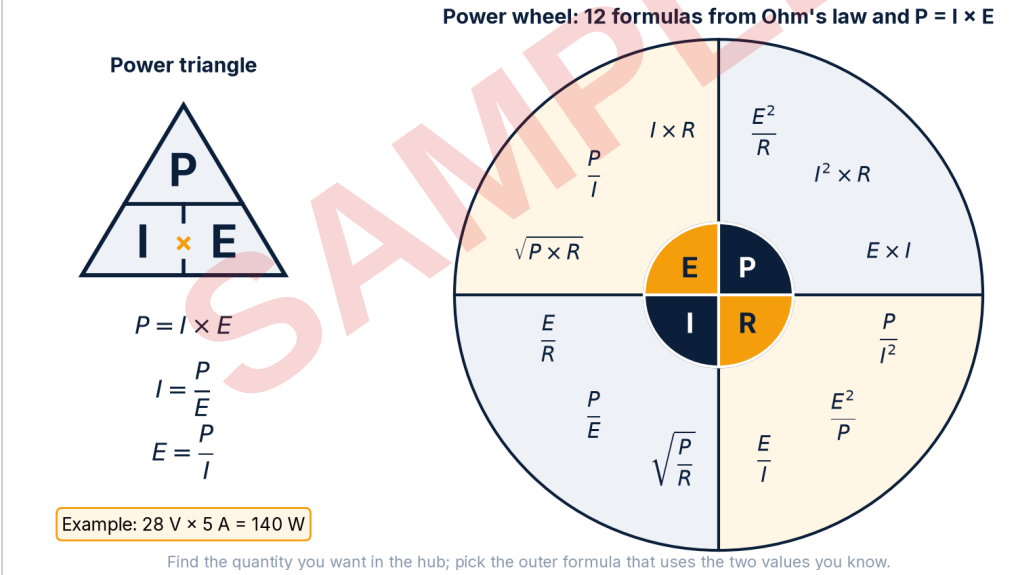


Figure 3-6. Left: the power triangle (P over I × E), used exactly like the Ohm's law triangle. Right: the power wheel. Find the wanted quantity in the hub, then choose the formula in its quadrant that uses the two values you know. Example: a 28-V, 5-A load uses 140 W, and its resistance is E ÷ I = 5.6 Ω.

SAMPLE

WORKED EXAMPLE

Worked Example 3-4. Power. A 28-V motor draws 15 A. (a) What power does it use? (b) What is that in horsepower, assuming 100 % efficiency?

(a) $P = I \times E = 15 \times 28 = 420\ W$

(b) $hp = \frac{420}{746} = 0.56\ hp$

The motor uses **420 W**, which is **0.56 hp**.

WORKED EXAMPLE

Worked Example 3-5. Why I^2R matters. A wire run has 0.2 Ω of resistance. How much heat does it produce at 10 A and at 20 A?

$P_{10\ A} = I^2R = 10^2 \times 0.2 = 20\ W$

$P_{20\ A} = I^2R = 20^2 \times 0.2 = 80\ W$

Doubling current quadruples the heat. This is why wire size and circuit protection must match the load.

SAMPLE

3.4 Series Circuits

A **series circuit** has only one path for current. Everything in it carries the same current. Rules for series circuits:

1. **Current** is the same at every point: $I_T = I_1 = I_2 = I_3$.
2. **Resistance** adds: $R_T = R_1 + R_2 + R_3 + \ldots$
3. **Voltage drops** add up to the source voltage: $E_T = E_1 + E_2 + E_3 + \ldots$
4. The largest resistor has the largest voltage drop.
5. One open anywhere stops all current.

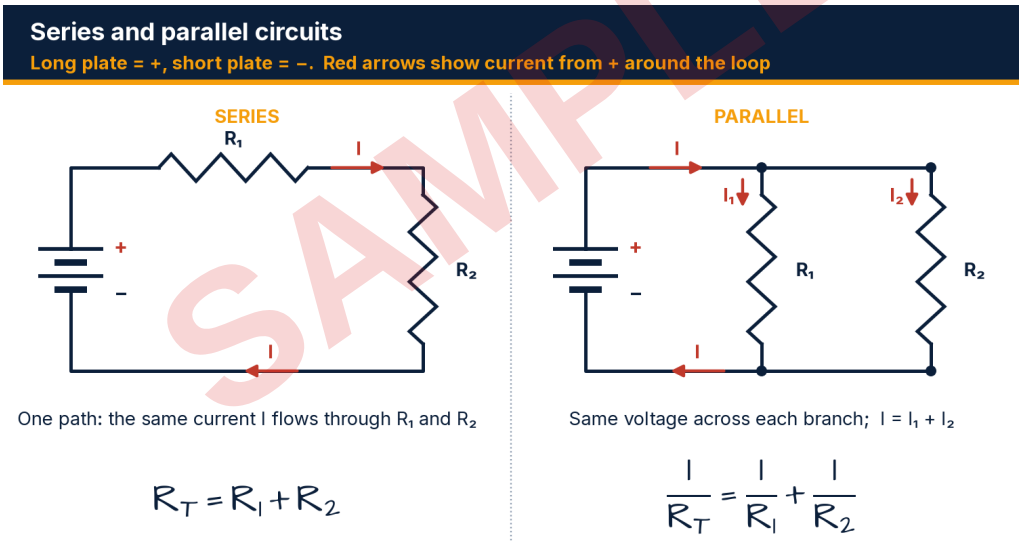


Figure 3-7. Series and parallel circuits. Left: R1 and R2 in series, so R = R1 + R2 and the same current flows through both. Right: two branches in parallel, so 1/R = 1/R1 + 1/R2 and each branch has the same voltage across it (1 = Branch 1, 2 = Branch 2).

SAMPLE

WORKED EXAMPLE

Worked Example 3-6. Series circuit. Resistors of 10 Ω, 20 Ω and 30 Ω are in series across 24 V. Find R_T, I and each voltage drop.

$$R_T = 10 + 20 + 30 = 60\ \Omega$$

$$I = \frac{E}{R_T} = \frac{24}{60} = 0.4\ \text{A}$$

$$E_1 = 0.4 \times 10 = 4\ \text{V}$$

$$E_2 = 0.4 \times 20 = 8\ \text{V}$$

$$E_3 = 0.4 \times 30 = 12\ \text{V}$$

R_T = 60 Ω, I = 0.4 A. Check: 4 + 8 + 12 = 24 V. ✓

Kirchhoff's voltage law

Kirchhoff's voltage law (KVL): the algebraic sum of the voltages around any closed loop is zero. Put another way, the voltage drops around a loop equal the source voltage. Example 3-6's check step is KVL in action.

SAMPLE

3.5 Parallel Circuits

A **parallel circuit** has two or more branches connected across the same source. Aircraft electrical buses are parallel circuits: each load gets full bus voltage, and switching one load off does not affect the others. Rules for parallel circuits:

1. **Voltage** is the same across every branch.
2. **Currents** in the branches add up to total current: $I_T = I_1 + I_2 + \ldots$
3. **Total resistance is always less than the smallest branch resistance.**
4. Adding branches *lowers* total resistance and *raises* total current.

Total resistance is found by one of three methods:

$$\text{General: } \frac{1}{R_T} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} + \ldots$$

$$\text{Two resistors: } R_T = \frac{R_1 \times R_2}{R_1 + R_2}$$

$$\text{N equal resistors: } R_T = \frac{R}{N}$$

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WORKED EXAMPLE

Worked Example 3-7. Equal resistors. Two 12-Ω resistors are in parallel.

$$R_T = \frac{R}{N} = \frac{12}{2} = 6\ \Omega$$

WORKED EXAMPLE

Worked Example 3-8. Unequal branches. Branches of 6 Ω, 3 Ω and 2 Ω are connected across a 12-V bus. Find R_T, each branch current and I_T.

$$\frac{1}{R_T} = \frac{1}{6} + \frac{1}{3} + \frac{1}{2}$$

$$= \frac{1}{6} + \frac{2}{6} + \frac{3}{6}$$

$$= \frac{6}{6}$$

$$R_T = 1\ \Omega$$

R_T = 1 Ω (less than the smallest branch, 2 Ω ✓).

$$I_1 = \frac{12}{6} = 2\ \text{A} \qquad I_2 = \frac{12}{3} = 4\ \text{A} \qquad I_3 = \frac{12}{2} = 6\ \text{A}$$

I_T = 12 A (and $\frac{12\ \text{V}}{1\ \Omega} = 12\ \text{A}$ ✓).

Kirchhoff's current law

Kirchhoff's current law (KCL): the current flowing into any junction equals the current flowing out of it. In Example 3-8, 12 A enters the junction and splits into 2 + 4 + 6 A.

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3.6 Series-Parallel Circuits

Real circuits combine both. Solve them by reducing step by step:

1. Find groups that are purely series or purely parallel, and replace each with its equivalent resistance.
2. Repeat until one equivalent resistance remains.
3. Find total current with Ohm's law, then work back out to find each voltage drop and branch current.

WORKED EXAMPLE

Worked Example 3-9. Series-parallel. A 4-Ω resistor (R_1) is in series with a parallel pair of 12 Ω (R_2) and 6 Ω (R_3). The source is 24 V.

Step 1.

$$R_2 \parallel R_3 = \frac{12 \times 6}{12 + 6} = \frac{72}{18} = 4\ \Omega$$

Step 2.

$$R_T = 4 + 4 = 8\ \Omega$$

$$I_T = \frac{24}{8} = 3\ \text{A}$$

R_T = 8 Ω, I_T = 3 A.

SAMPLE

WORKED EXAMPLE · CONTINUED

Step 3.

$$E_1 = 3 \times 4 = 12 \text{ V}$$

$$E_{2,3} = 3 \times 4 = 12 \text{ V}$$

Check: $12 + 12 = 24$ V ✓

Step 4.

$$I_2 = \frac{12}{12} = 1 \text{ A} \qquad I_3 = \frac{12}{6} = 2 \text{ A}$$

(1 + 2 = 3 A ✓)

Opens and shorts

An **open circuit** is a break in the current path; current stops in that path and the full source voltage appears across the break. A **short circuit** is an unintended low-resistance path; current rises sharply, which is why every aircraft circuit is protected by a fuse or circuit breaker. Circuit protection is sized to protect the *wire*, not the load.

SAMPLE

Chapter 5. Weight and Balance

CHAPTER OBJECTIVES

Learning objectives. After studying this chapter you should be able to:

1. Define weight-and-balance terms, including datum, arm, moment, CG, MAC and the empty-weight configuration.
2. Explain why aircraft are weighed and how to prepare the aircraft and the weighing area.
3. Jack an aircraft safely for weighing or maintenance.
4. Calculate arm, positive and negative moments, center of gravity and moment index.
5. Explain the purpose of weight and CG limits and determine the CG.
6. Check whether adverse loading puts the CG out of limits.
7. Compute the effect of equipment changes and the placement of ballast.

ACS reference: AM.I.C (Weight and Balance). **Kit practice topic:** WB.

SAMPLE

An aircraft that is too heavy needs more runway, climbs poorly and overstresses its structure. One whose center of gravity is out of limits may be impossible to control: too far forward and the elevator cannot raise the nose for landing;

too far aft and the aircraft becomes unstable and may not recover from a stall or spin. The mechanic keeps the weight-and-balance records current after every change, and the pilot uses them to load the aircraft on every flight.

5.1 Terminology

The **datum** is an imaginary vertical plane from which all horizontal distances are measured. The manufacturer chooses it: often the firewall, the wing leading edge, the nose, or a point ahead of the nose so that every arm is positive. Its location is given in the Type Certificate Data Sheet (TCDS) or the aircraft's weight-and-balance data (Figure 5-1).

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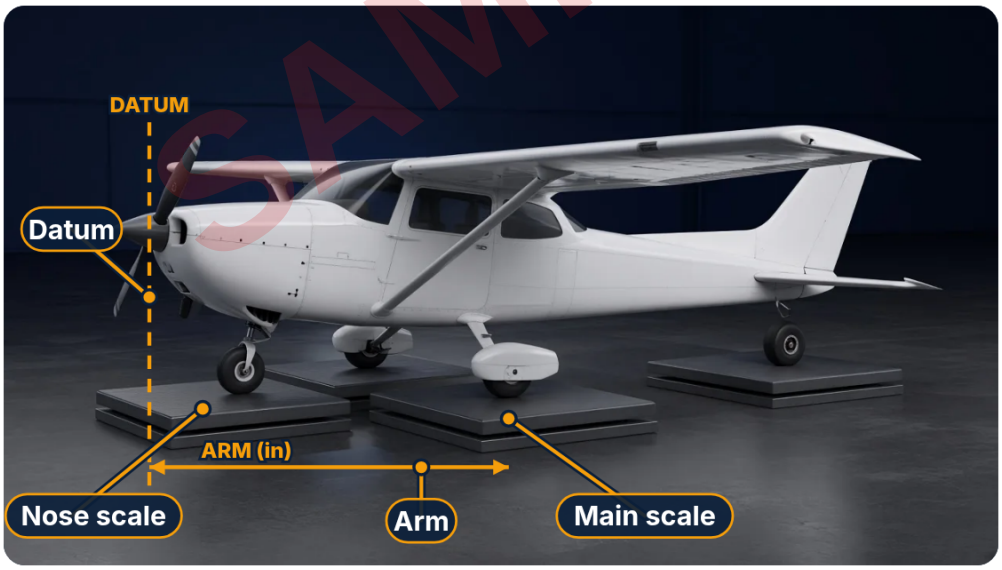


Figure 5-1. The datum and the weighing points. Every arm is measured from the datum, parallel to the longitudinal axis.

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- **Arm:** the horizontal distance, in inches, from the datum to the center of gravity of an item. Arms aft of the datum are positive (+); arms forward of it are negative (−).
- **Moment:** weight multiplied by arm, in pound-inches (lb-in). A weight forward of the datum produces a negative moment.
- **Center of gravity (CG):** the point at which the aircraft would balance if suspended. CG = total moment ÷ total weight.
- **Moment index:** a moment divided by a reduction factor such as 100 or 1,000 to make large numbers easier to handle.
- **Mean aerodynamic chord (MAC):** the chord of an imaginary rectangular wing with the same aerodynamic characteristics as the actual wing. On larger aircraft, the CG is expressed as a percentage of MAC.
- **CG range:** the distance between the forward and aft CG limits.
- **Tare:** the weight of chocks, blocks or other equipment on the scales during weighing. It is subtracted from the scale reading.
- **Maximum weight** (maximum certificated gross weight), **maximum ramp weight**, **maximum landing weight** and **maximum zero-fuel weight** are limits found in the TCDS, the POH or the AFM.

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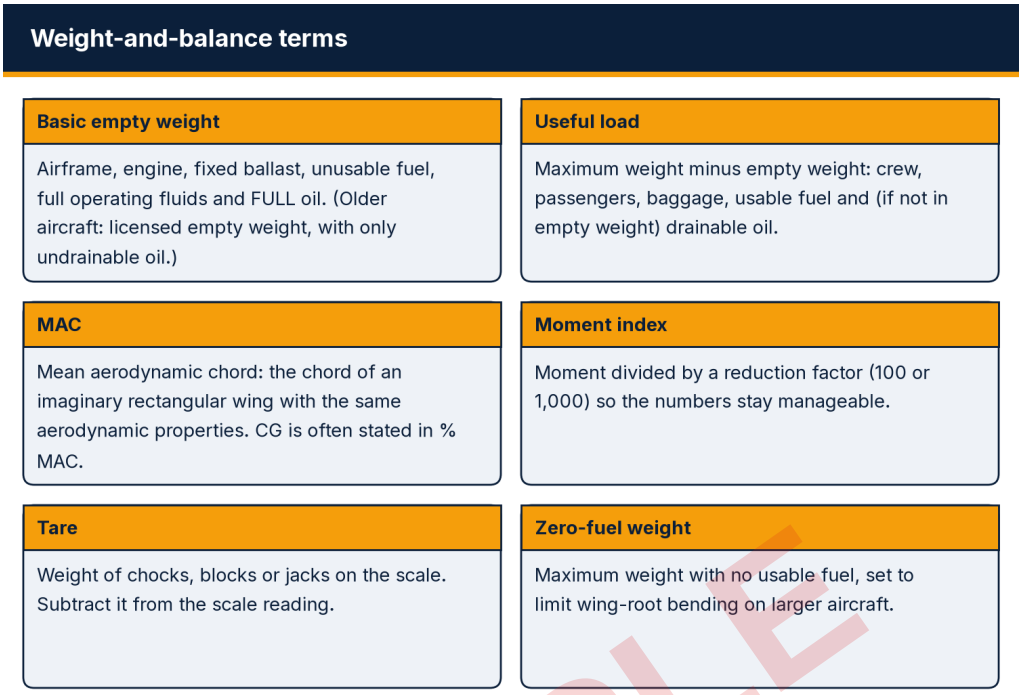


Figure 5-2. Key weight-and-balance terms.

Empty-weight configuration

The aircraft must be weighed in the configuration that defines its empty weight.

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- **Basic empty weight** (GAMA standard, used for most aircraft built since the late 1970s): airframe, engines, all permanently installed equipment, fixed ballast, **unusable fuel, full operating fluids and full engine oil**.
- **Licensed empty weight** (older aircraft): the same, but including only **undrainable oil** rather than full oil.
- **Useful load:** maximum weight minus empty weight. It includes the pilot, passengers, baggage, usable fuel and, where applicable, drainable oil.

The TCDS notes tell you what must be included: for example, "Fuel: unusable fuel of 12 lb at +46 in must be included in empty weight."

5.2 Why and How Aircraft Are Weighed

Aircraft are weighed when manufactured, and again when the empty weight is in doubt: after major repairs or alterations, after an overhaul or repaint, when an operator's program requires it, or when the records are lost or unreliable. Small changes in installed equipment are normally *calculated* rather than weighed (section 5.5). Weight tends to creep up over the years as paint, dirt, repairs and wiring accumulate.

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The weighing area and preparation

Weigh the aircraft in a **closed hangar**, out of the wind, on a level floor (Figure 5-3). Even a light breeze over the wing changes the scale readings.

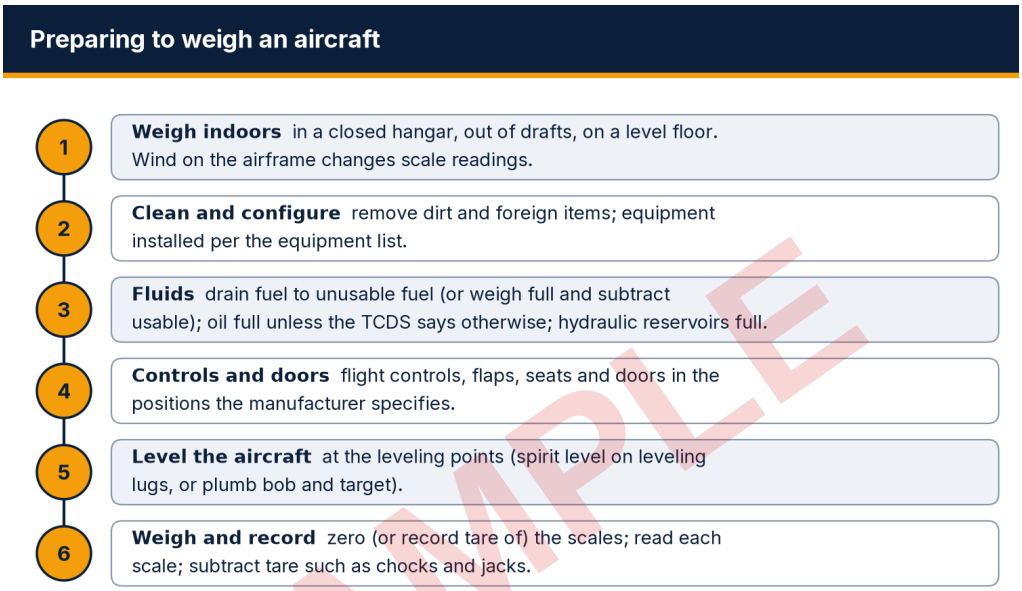


Figure 5-3. Preparing the aircraft and the area for weighing.

SAMPLE

1. Clean the aircraft and remove items that are not part of the empty weight.
2. Check the equipment list against what is installed.
3. Drain the fuel until only unusable fuel remains, or weigh with full tanks and subtract the usable fuel weight (6 lb/gal for avgas) and its moment. Fill the oil (basic empty weight) and the hydraulic reservoirs.
4. Put the seats, flaps, controls and doors in the positions the manufacturer specifies.
5. **Level the aircraft** using the method given by the manufacturer: a spirit level on leveling lugs or screws, or a plumb bob over a target.
6. Zero the scales and note any tare, then record each scale reading.

Scales. Platform scales, electronic load cells placed under the wheels, or load cells placed on top of jacks at the jack points are used. Load-cell weighing on jacks is common for large aircraft because it levels and weighs at the same time.

SAMPLE

Jacking

Jacking an aircraft is hazardous. Use only the manufacturer’s jack points and the correct jack pads, on a level floor with the aircraft in a hangar.

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- Check the jacks' rated capacity and condition, and make sure safety locks or collars work.
- Raise all jacks evenly so the aircraft stays level and no jack carries an unbalanced load.
- Run the safety collar down as the jack rises.
- Use a tail stand or ballast if the manufacturer calls for it, to prevent the aircraft tipping.
- Never work under an aircraft supported only by jacks without the locks set; keep people out of the aircraft while it is being jacked.
- When jacking one wheel to change a tire, use the specified axle jack and chock the other wheels.

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5.3 Calculating Arm, Moment and CG

The basic method is always the same: multiply each weight by its arm to get its moment, add the weights and the moments, and divide total moment by total weight (Figure 5-4).

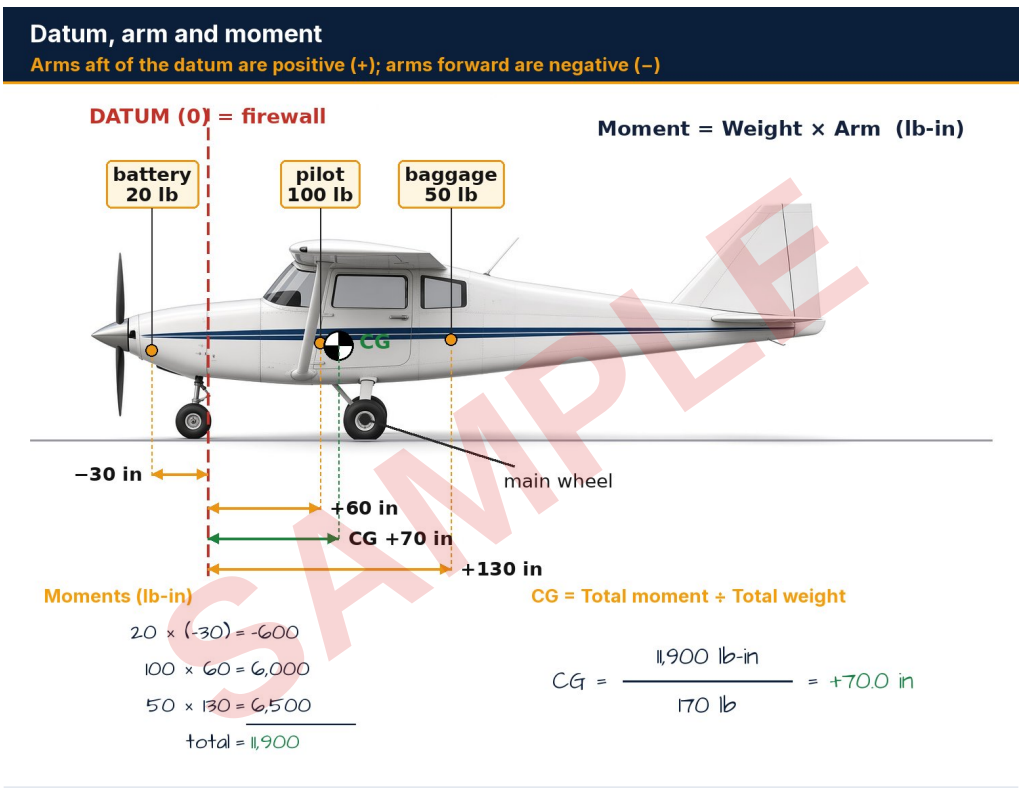


Figure 5-4. Datum, arm and moment. Items forward of the datum have negative arms and negative moments.

$$CG = \frac{\Sigma \text{ Moments}}{\Sigma \text{ Weights}}$$

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WORKED EXAMPLE

Worked Example 5-1. A tailwheel airplane is weighed with the datum at the wing leading edge. The main wheels are 10 in aft of the datum and the tail wheel is 220 in aft. Scale readings: left main 650 lb, right main 652 lb, tail 140 lb. Tare: 5 lb on each main scale (chocks), 8 lb on the tail scale (a stand). Find the empty weight and CG.

$$\begin{aligned}
\text{Left main} &= 650 - 5 = 645 \text{ lb} \\
\text{Right main} &= 652 - 5 = 647 \text{ lb} \\
\text{Tail} &= 140 - 8 = 132 \text{ lb} \\
\text{Total weight} &= 645 + 647 + 132 = 1{,}424 \text{ lb} \\
\text{Total moment} &= 6{,}450 + 6{,}470 + 29{,}040 \\
&= 41{,}960 \text{ lb-in}
\end{aligned}$$

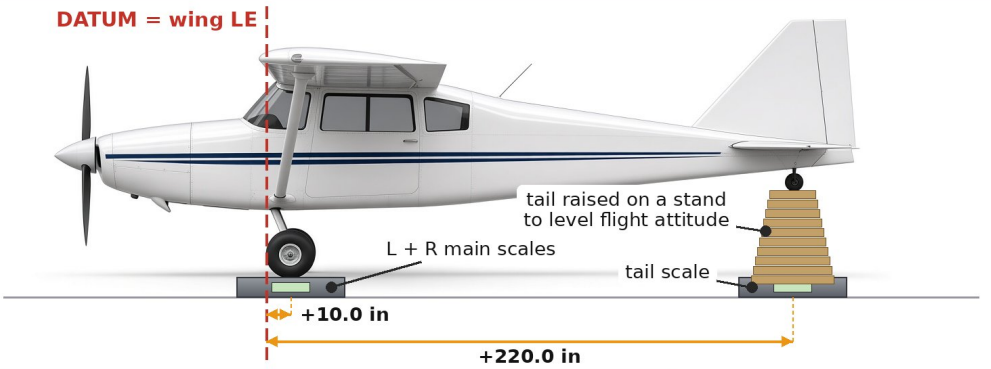
$$\text{CG} = \frac{\text{total moment}}{\text{total weight}} = \frac{41{,}960}{1{,}424} = +29.5 \text{ in}$$

The CG is **+29.5 in** aft of the datum (Figure 5-5).

SAMPLE

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Worked weighing problem (tailwheel aircraft, datum at wing leading edge)



Point	Scale (lb)	Tare (lb)	Net (lb)	Arm (in)	Moment (lb-in)
Left main	650	5	645	+10.0	6,450
Right main	652	5	647	+10.0	6,470
Tail	140	8	132	+220.0	29,040
Total			1,424	+29.5	41,960

Net = Scale − Tare

Moment = Net × Arm

$$CG = \frac{41{,}960 \text{ lb-in}}{1{,}424 \text{ lb}}$$

= +29.5 in aft of datum

Figure 5-5. The weighing calculation laid out as a table. Always subtract tare before computing moments.

SAMPLE

WORKED EXAMPLE

Worked Example 5-2. A nosewheel aircraft has its datum 50 in *aft* of the nose wheel. The nose wheel reads 500 lb and the two mains together read 1,800 lb at an arm of +20 in. Find the CG.

Nose moment = 500 × (−50) = −25,000

Main moment = 1,800 × 20 = 36,000

Total moment = −25,000 + 36,000 = 11,000 lb-in

Total weight = 500 + 1,800 = 2,300 lb

$$CG = \frac{11{,}000}{2{,}300} = +4.8 \text{ in}$$

The CG is **+4.8 in**.

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When the CG is expressed in percent MAC:

$$\%\ \text{MAC} = \frac{\text{CG} - \text{LEMAC}}{\text{MAC}} \times 100$$

where LEMAC is the arm of the leading edge of the MAC.

WORKED EXAMPLE

Worked Example 5-3. The CG is at +165 in, LEMAC is at +150 in, and the MAC is 60 in long. What is the CG in % MAC?

$$\%\ \text{MAC} = \frac{\text{CG} - \text{LEMAC}}{\text{MAC}} \times 100$$
$$= \frac{165 - 150}{60} \times 100$$
$$= 25\%\ \text{MAC}$$

The CG is at **25 % MAC**.

SAMPLE

5.4 Weight and CG Limits; Adverse Loading

Limits are set by the manufacturer and approved during certification. They appear in the TCDS, the AFM/POH or the weight-and-balance report. Weight limits protect the structure and performance; CG limits ensure the aircraft is stable and controllable (Figure 5-6).

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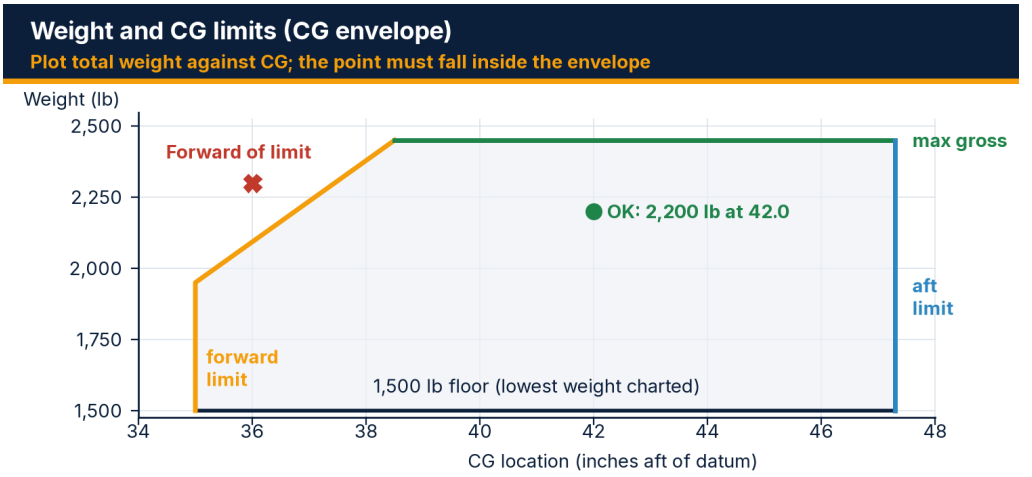


Figure 5-6. A CG envelope. Many aircraft have a forward limit that moves aft at higher weights.

- **Forward CG** increases stability but makes the aircraft nose-heavy: higher stick forces, higher stall speed, and possibly too little elevator authority to flare.
- **Aft CG** makes the aircraft less stable and easier to over-control; at the extreme it may not recover from a stall or spin.

Adverse-loading checks

After a major alteration or a new weighing, the mechanic may perform **adverse-loading checks** to prove the CG cannot go out of limits under any reasonable loading.

SAMPLE

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- **Forward adverse-loading check:** load the useful load items that have arms *forward* of the forward CG limit (pilot, front passenger, fuel if it is forward) with the minimum fuel, and leave empty all positions aft of the limit. Compute the CG and make sure it is not forward of the forward limit.
- **Aft adverse-loading check:** load all items aft of the aft CG limit to their maximum (rear seats, baggage, fuel if aft) with only the minimum required forward items (a lightweight pilot, typically 170 lb), and check that the CG is not aft of the aft limit.

WORKED EXAMPLE

Worked Example 5-4. Empty weight 1,500 lb at +36.0 in (moment 54,000). Aft CG limit is +46.0 in. For the aft check, load a 170-lb pilot at +37, 340 lb of rear passengers at +73, 100 lb of baggage at +95, and minimum fuel of 30 lb at +48. Is the CG within the aft limit?

$$\text{Moments} = 54{,}000 + 6{,}290 + 24{,}820 + 9{,}500 + 1{,}440$$
$$= 96{,}050 \text{ lb-in}$$
$$\text{Weight} = 1{,}500 + 170 + 340 + 100 + 30 = 2{,}140 \text{ lb}$$
$$\text{CG} = \frac{96{,}050}{2{,}140} = +44.9 \text{ in}$$

The CG is **+44.9 in**, which is forward of +46.0, so **within limits**.

SAMPLE

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5.5 Equipment Changes and Ballast

Equipment changes

When equipment is added, removed or relocated, compute the new empty weight and CG rather than reweighing. Add the weight and moment of items installed; subtract the weight and moment of items removed. Record the change in the weight-and-balance record and update the equipment list.

WORKED EXAMPLE

Worked Example 5-5. Empty weight is 1,800 lb with a CG of +40.0 in (moment 72,000). A 12-lb radio at +60 in is removed and a 20-lb radio is installed at +55 in. Find the new empty weight and CG.

$$\text{New weight} = 1{,}800 - 12 + 20 = 1{,}808 \text{ lb}$$

$$\text{New moment} = 72{,}000 - 720 + 1{,}100 = 72{,}380 \text{ lb-in}$$

$$\text{CG} = \frac{72{,}380}{1{,}808} = +40.03 \text{ in}$$

The new CG is **+40.03 in**.

A shortcut for shifting an item:

$$\text{Change in CG} = \frac{\text{weight shifted} \times \text{distance shifted}}{\text{total weight}}$$

Ballast

Ballast is weight added to bring the CG within limits.

SAMPLE

- **Temporary ballast** (lead shot bags, sandbags) is carried for particular flights, such as flying solo from the rear seat of a tandem trainer. It must be placarded and secured.
- **Permanent ballast** (lead plates) is installed to correct a CG shifted by a modification. It is bolted to structure strong enough to carry it, painted red and placarded "Permanent ballast — do not remove," and its weight is included in the empty weight.

The weight of ballast needed is found from:

$$\text{Ballast weight} = \frac{\text{aircraft weight} \times \text{distance CG is out of limits}}{\text{distance from ballast arm to desired CG}}$$

WORKED EXAMPLE

Worked Example 5-6. An aircraft weighs 2,000 lb with its CG at +31.0 in. The forward limit is +33.0 in. How much ballast at +200 in brings the CG to the forward limit?

$$\text{Ballast} = \frac{2{,}000 \times (33.0 - 31.0)}{200 - 33}$$

$$= \frac{4{,}000}{167}$$

$$= 24.0 \text{ lb}$$

Add **24.0 lb** of ballast.

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KEY NUMBERS

Key numbers

- Avgas 6 lb/gal; Jet A 6.7 lb/gal; oil 7.5 lb/gal; water 8.35 lb/gal.
- CG = total moment ÷ total weight. Moment = weight × arm.
- % MAC = (CG − LEMAC) ÷ MAC × 100.
- Standard pilot/passenger weight in many POH examples: 170 lb.

EXAM TRAP

Common exam traps

- *Forgetting tare.* Subtract it before you compute any moment.
- *Signs.* An arm forward of the datum is negative, so removing weight forward of the datum adds a **positive** moment change.
- *Basic vs. licensed empty weight.* Basic includes **full oil**; licensed includes only undrainable oil. Both include unusable fuel.
- *Where to find the datum and CG limits.* The TCDS (or the aircraft specification for older types) and the weight-and-balance data.
- *Wind.* Weigh inside a closed hangar.

SAMPLE

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5.6 Chapter Review

Summary. Weight and balance starts at the datum. Every item has a weight, an arm and a moment, and the CG is total moment divided by total weight. Aircraft are weighed in a closed hangar, level, in the empty-weight configuration given by the manufacturer, with tare subtracted. Jacking requires the correct jack points, even lifting and safety locks. Limits keep the aircraft strong and controllable; adverse-loading checks prove they cannot be exceeded. Equipment changes are computed, and ballast corrects a CG that is out of limits.

Review questions (answers follow).

1. A 20-lb item is located 15 in forward of the datum. What is its moment?
2. An aircraft weighs 2,500 lb with a total moment of 95,000 lb-in. Where is its CG?
3. Name two items included in basic empty weight that are excluded from useful load.
4. A scale reads 820 lb with 12 lb of chocks on it. What is the net weight?
5. LEMAC is at +80 in and MAC is 50 in. The CG is +92.5 in. What is the CG in % MAC?
6. Why must an aircraft be weighed inside a closed hangar?
7. A 1,600-lb aircraft has its CG at +35 in. A 10-lb battery is moved from +60 in to +10 in. What is the new CG?
8. What markings are required for permanent ballast?

SAMPLE

Answers. (1) −300 lb-in. (2) +38.0 in. (3) Unusable fuel and full oil (or undrainable oil), fixed ballast. (4) 808 lb. (5) $\frac{92.5 - 80}{50} \times 100 = 25$ % MAC. (6) Wind changes the scale readings. (7) $\Delta CG = \frac{10 \times (-50)}{1{,}600} = -0.31$ in; new CG = +34.69 in. (8) It is typically painted red and placarded "Permanent ballast — do not remove," and its weight and location are recorded in the weight-and-balance data.

Practice in the kit. Work the WB topic in the General kit.

References. FAA-H-8083-30B, *Aviation Maintenance Technician Handbook—General,* Chapter 6, Aircraft Weight and Balance. FAA-H-8083-1B, *Aircraft Weight and Balance Handbook*. FAA-S-ACS-1, Area I.C.

SAMPLE