PRIVATE PILOT STUDY GUIDE

Weight & Balance

A complete guide to understanding, calculating, and applying weight and balance principles for safe flight operations.

WEIGHT AND BALANCE | CENTER OF GRAVITY | MOMENT | AIRCRAFT LOADING | CG LIMITS | USEFUL LOAD

WHY THIS IS SAFETY CRITICAL

Weight and balance is one of the pilot in command's most basic preflight responsibilities. Every flight begins with a loaded aircraft, and every loaded aircraft has a center of gravity. If that CG is outside the approved envelope, the aircraft may be uncontrollable. If the aircraft is over maximum gross weight, structure and performance are compromised.

This is not paperwork. It is a safety of flight decision. Under 14 CFR 91.9, the pilot must comply with operating limitations in the approved AFM or POH, including weight and CG limits. On a practical test, expect to calculate the actual aircraft you are flying and explain what the numbers mean in the real airplane.

WHAT EXCESS WEIGHT DOES

AREA	EFFECT
Takeoff	Higher takeoff speed and longer ground roll.
Climb	Reduced climb rate, reduced climb angle, and lower service ceiling.
Cruise	Reduced speed and shorter range for the same fuel.
Handling	Reduced maneuverability and higher control loads.
Stall	Higher stall speed because the wing must produce more lift.
Landing	Higher approach speed, longer landing roll, and more landing gear stress.

Instructor Emphasis

Published stall speeds are tied to a published weight. Heavier aircraft stall faster. Lighter aircraft stall slower. If the airplane is overweight, the familiar book speeds no longer tell the whole story.

CHECKRIDE

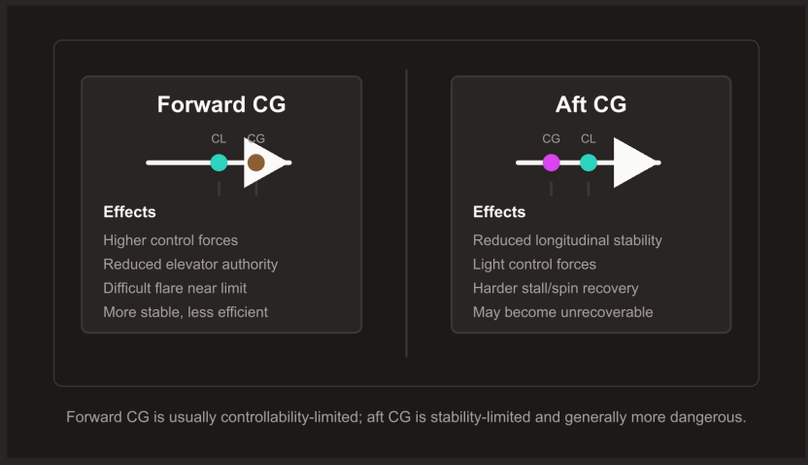
If asked whether you can always depart at maximum gross weight, the answer is no. Weight and balance proves the loading is legal. Performance charts prove whether that legal loading is safe for runway, temperature, obstacles, and density altitude.

MEMORY ANCHOR

Weight is a multiplier. It makes every performance problem larger, more runway, less climb, faster stall, and less margin.

CENTER OF GRAVITY CONTROLS STABILITY

The center of gravity is the theoretical point where the aircraft's weight is concentrated. It is expressed as inches from the datum, or as percent MAC on larger aircraft. The manufacturer establishes a forward limit and an aft limit. Both matter, but for different reasons.



Forward CG is usually controllability-limited; aft CG is stability-limited and generally more dangerous.

FORWARD CG

- Nose heavy feel with higher control forces.
- More up elevator is required to flare.
- At the extreme, the aircraft may not raise the nose enough for landing.
- Stall speed increases and cruise efficiency decreases because the tail must create more download.
- Tricycle gear aircraft place more load on the nosewheel.

AFT CG

- Tail heavy feel with lighter control forces.
- Longitudinal stability decreases.
- The aircraft may not return toward level flight on its own.
- Stall and spin recovery may become difficult or impossible.
- Beyond the aft limit, loss of control is possible.

Common Mistake

Do not treat forward and aft CG as equally bad. Forward CG can prevent a normal flare. Aft CG attacks stability and recovery. The aft condition is usually the more dangerous one.

EXAMINER QUESTION

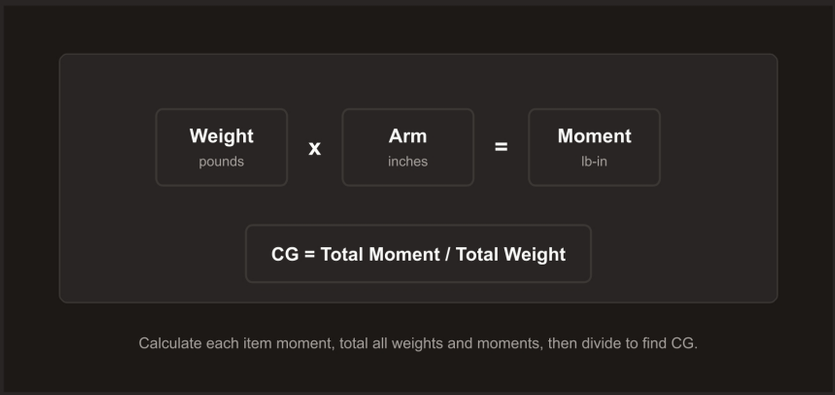
What happens if the CG is aft of limits? Answer with reduced stability, light control forces, difficult stall and spin recovery, and possible unrecoverable control loss.

LATERAL BALANCE

Longitudinal CG gets most of the attention, but lateral imbalance matters too. A full tank on one side and an empty tank on the other can require continuous aileron input, create drag, and increase pilot workload. Most small aircraft do not require a formal lateral calculation, but fuel management limits in the POH still matter.

THE TEETER TOTTER PRINCIPLE

Weight and balance math is physics. Weight multiplied by distance from the datum creates moment. Total moment divided by total weight gives the CG location. Then you compare that location to the approved envelope for the aircraft and category of operation.



MOMENT

Moment = Weight x Arm

Calculate one item at a time.

CG

CG = Total Moment / Total Weight

Compare to the POH envelope.

SHIFT

CG Shift = Weight Moved x Distance / Total Weight

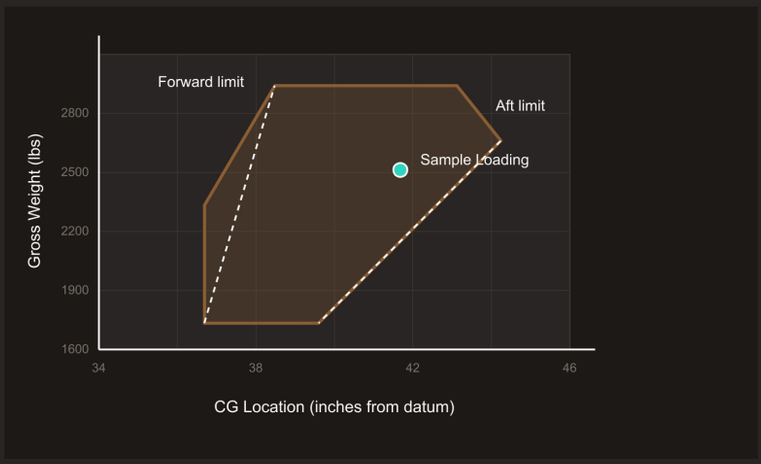
The CG moves toward the relocated item.

TERMS YOU MUST OWN

- Datum, imaginary reference plane chosen by the manufacturer.
- Arm, distance in inches from datum to the item.
- Moment, weight times arm.
- Station, a location identified by inches from datum.
- Moment index, moment divided by a constant to keep numbers manageable.

Moment Index Trick

If the aircraft uses reduced moments, divide every moment by the same constant, including empty weight. Confirm the envelope uses the same reduced units before plotting.



Envelope Trap

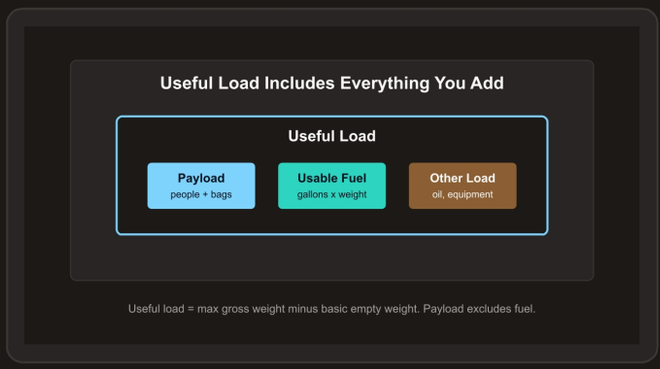
The envelope is not always a rectangle. Some charts have angled edges, notched corners, separate normal and utility limits, or changing limits at different weights. Trace the actual boundary.

PRACTICAL TEST

Be ready to walk through today's calculation using current aircraft records, actual people, fuel, baggage, total weight, total moment, calculated CG, and a clear go or no go conclusion.

LOADING VOCABULARY

TERM	MEANING
Basic empty weight	Standard empty weight plus installed optional equipment. Use the current aircraft record.
Useful load	Maximum gross weight minus basic empty weight. Includes people, baggage, and usable fuel.
Payload	Occupants, cargo, and baggage only. Fuel is not payload.
Ramp weight	Maximum ground operation weight, including taxi and runup fuel.
Takeoff weight	Weight at the start of the takeoff roll.
Zero fuel weight	Aircraft and load except usable fuel. Important when published as a structural limit.

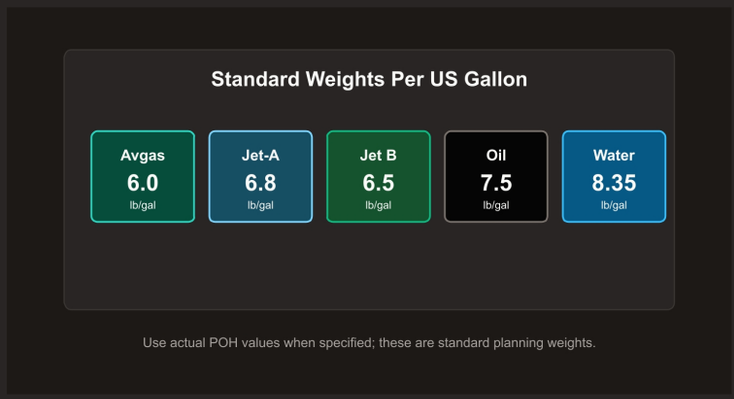


Wrong Empty Weight

Do not use the sample loading problem in the POH as the aircraft's actual empty weight. Use the current weight and balance record kept with the aircraft documents.

Back Seats Move CG Aft

Rear seats usually have a longer arm than front seats. Heavy rear passengers and baggage can move the CG aft quickly. Redistribute load before trying to make the math agree.



USEFUL LOAD

Useful Load = Max Gross Weight minus Basic Empty Weight

Fuel reduces what remains for people and baggage.

AVGAS

Fuel Weight = Gallons x 6

Forty gallons of 100LL weighs 240 pounds.

FUEL BURN

Check both takeoff and planned landing CG. Wing fuel close to the CG may change little. Fuselage tanks or multiple tank locations can move CG enough to matter.

UNUSABLE FUEL

Unusable fuel is already included in basic empty weight. Add only usable fuel to the loading calculation.

14 CFR 91.9
The pilot must comply with operating limitations in the approved AFM or POH. Weight and CG limits are operating limitations, so being outside them is not legal just because no form was filled out.

14 CFR 91.7
The pilot in command determines whether the aircraft is airworthy before flight. An aircraft loaded outside limits is not in an airworthy condition.

WHERE LIMITS COME FROM
Manufacturers establish weight and CG ranges through flight testing and structural analysis. The TCDS is the official FAA source and the POH should match it.

PLACARDS
Baggage compartment and seating placards are limitations. Exceeding a placarded compartment limit can violate the rules even if total gross weight is legal.

RECORDS MUST BE CURRENT

Any installed or removed equipment changes empty weight and moment. The mechanic performing the work must update the aircraft weight and balance records. Added avionics, ADS B equipment, removed seats, fixed ballast, or special equipment can all change the baseline used by the pilot.

The current empty weight, moment, and equipment list must be aboard the aircraft. Flight planning apps can speed up the math, but only if the profile uses current records, correct fuel, correct station arms, and actual loading.

SCENARIO, FULL FLIGHT
Four adults, full fuel, and full baggage often will not work in a two plus two trainer. Identify whether weight or CG is binding, then reduce fuel, baggage, or passengers.

SCENARIO, AFTER FUEL BURN
If departure is legal, verify landing too. Plot takeoff and estimated landing on the same envelope when fuel burn may shift CG.

CHECKRIDE ANSWERS TO HAVE READY

OVER GROSS
Higher stall speed, longer takeoff roll, reduced climb, reduced range, longer landing roll, and reduced structural margin.

FORWARD CG
Nose heavy, high control forces, reduced elevator authority, higher stall speed, and possible inability to flare.

AFT CG
Tail heavy, reduced stability, light controls, difficult stall and spin recovery, and possible loss of control.

DOCUMENTS
Use the current aircraft weight and balance records for empty weight and moment, and the POH plus TCDS for authorized limits.

ARROW Reminder
Airworthiness certificate, Registration, Radio station license if required, Operating handbook, and Weight and balance data.

Tailwheel Note
On tailwheel aircraft, forward CG can increase the tendency to nose over during landing. Use the specific POH language for that aircraft.