



Commercial Pilot Ground School

Day 10

Forces of Flight, Load Factor, Vg Diagram, Stability, Aerodynamics in Maneuvers



Agenda

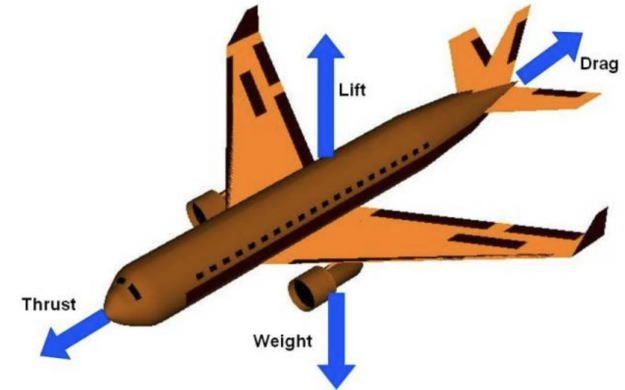
- Forces in Flight
 - Lift
 - Drag
 - Thrust
 - Weight
- Load Factor
- V_g Diagram

Forces in Flight

The four forces acting on an aircraft in straight-and-level, unaccelerated flight are thrust, drag, lift, and weight. They are defined as follows:

- Thrust—the forward force produced by the powerplant/ propeller or rotor. It opposes or overcomes the force of drag. As a general rule, it acts parallel to the longitudinal axis. However, this is not always the case, as explained later.
- Drag—a rearward, retarding force caused by disruption of airflow by the wing, rotor, fuselage, and other protruding objects. As a general rule, drag opposes thrust and acts rearward parallel to the relative wind.

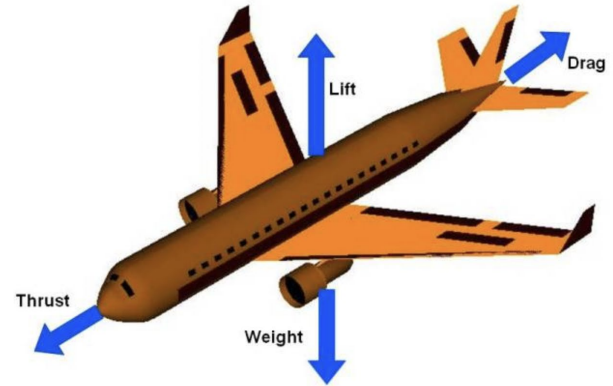
Four Forces on an Airplane



Forces in Flight

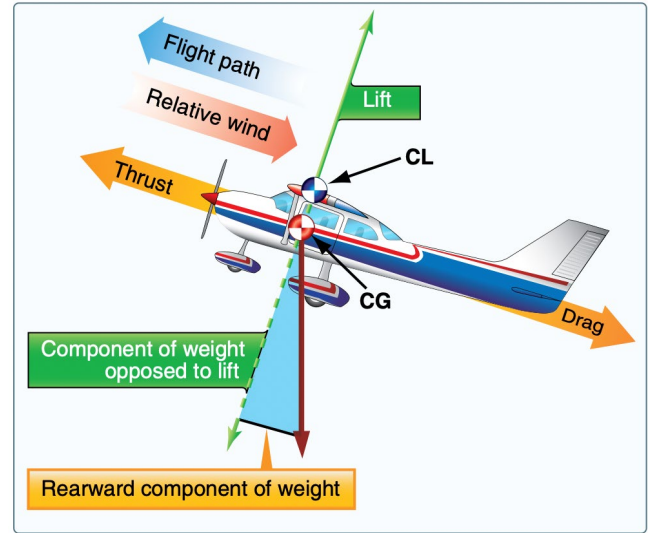
- Lift—is a force that is produced by the dynamic effect of the air acting on the airfoil, and acts perpendicular to the flight path through the center of lift (CL) and perpendicular to the lateral axis. In level flight, lift opposes the downward force of weight.
- Weight—the combined load of the aircraft itself, the crew, the fuel, and the cargo or baggage. Weight is a force that pulls the aircraft downward because of the force of gravity. It opposes lift and acts vertically downward through the aircraft's center of gravity (CG).

Four Forces on an Airplane



Thrust

For an aircraft to start moving, thrust must be exerted and be greater than drag. The aircraft continues to move and gain speed until thrust and drag are equal. In order to maintain a constant airspeed, thrust and drag must remain equal, just as lift and weight must be equal to maintain a constant altitude. If in level flight, the engine power is reduced, the thrust is lessened, and the aircraft slows down. As long as the thrust is less than the drag, the aircraft continues to decelerate. To a point, as the aircraft slows down, the drag force will also decrease. The aircraft will continue to slow down until thrust again equals drag at which point the airspeed will stabilize.

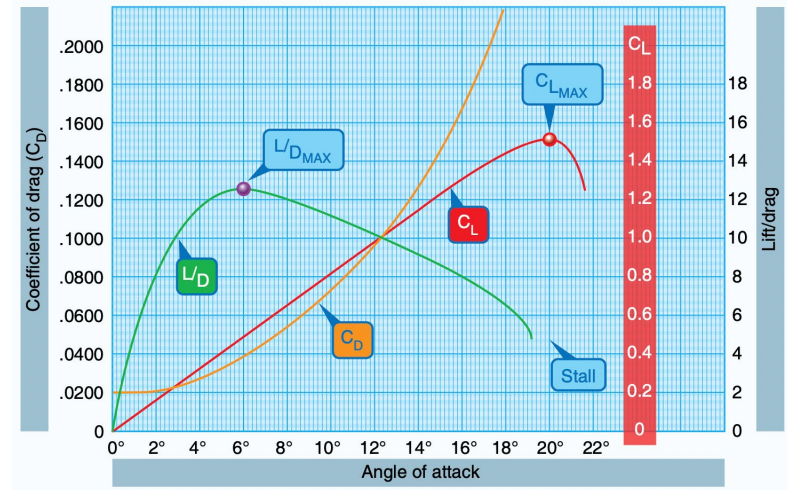


Lift

The pilot can control the lift. Any time the control yoke or stick is moved fore or aft, the AOA is changed. As the AOA increases, lift increases (all other factors being equal). When the aircraft reaches the maximum AOA, lift begins to diminish rapidly. This is the stalling AOA, known as CL-MAX critical AOA.

The lift equation shows that doubling of the airspeed will result in four times the lift. When examining the equation, lift (L) is determined through the relationship of the air density (ρ), the airfoil velocity (V), the surface area of the wing (S) and the coefficient of lift (CL) for a given airfoil.

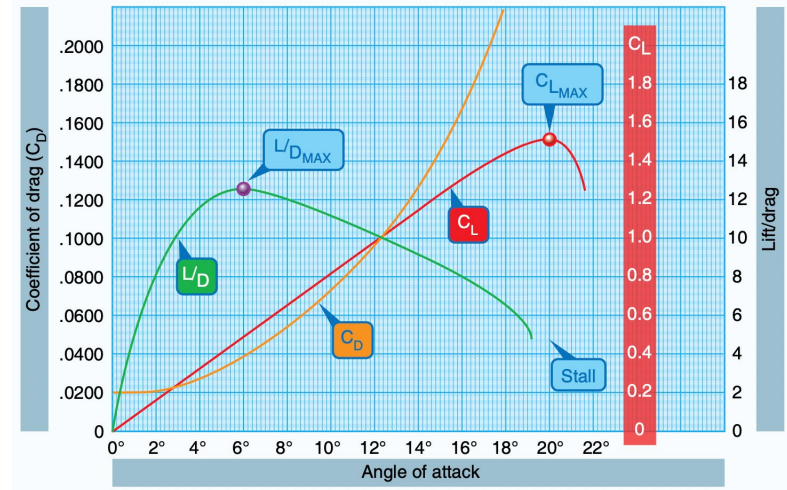
$$L = \frac{C_L \cdot \rho \cdot V^2 \cdot S}{2}$$



Lift

All other factors being constant, for every AOA there is a corresponding airspeed required to maintain altitude in steady, unaccelerated flight (true only if maintaining level flight). Since an airfoil always stalls at the same AOA, if increasing weight, lift must also be increased.

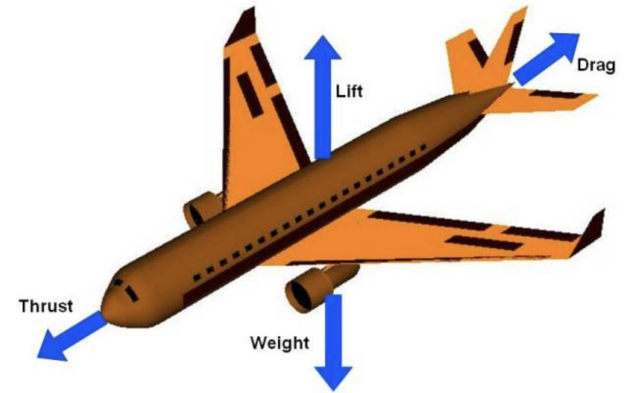
$$L = \frac{C_L \cdot \rho \cdot V^2 \cdot S}{2}$$



Drag

Drag is the force that resists movement of an aircraft through the air. There are two basic types: parasite drag and induced drag. The first is called parasite because it in no way functions to aid flight, while the second, induced drag, is a byproduct of an airfoil developing lift.

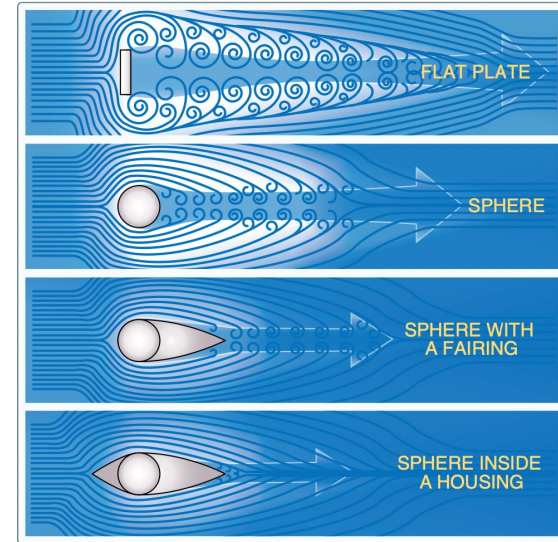
Four Forces on an Airplane



Parasite Drag

Parasite drag is made of all the forces that work to slow an aircraft. This includes the displacement of the air by the aircraft, turbulence generated in the airstream, or a hindrance of air moving over the surface of the aircraft and airfoil. There are three types of parasite drag: form drag, interference drag, and skin friction.

- **Form Drag-** Form drag is the portion of parasite drag generated by the aircraft due to its shape and airflow around it. Examples include the engine cowlings, antennas, and the aerodynamic shape of other components.



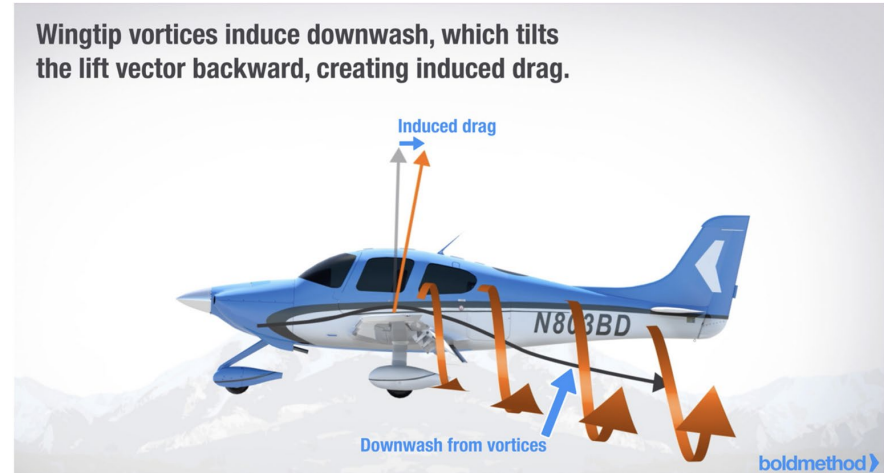
Parasite Drag

- Interference Drag- Interference drag comes from the intersection of airstreams that creates eddy currents, turbulence, or restricts smooth airflow. For example, the intersection of the wing and the fuselage at the wing root has significant interference drag.
- Skin Friction Drag- Skin friction drag is the aerodynamic resistance due to the contact of moving air with the surface of an aircraft. Every surface, no matter how apparently smooth, has a rough, ragged surface when viewed under a microscope.



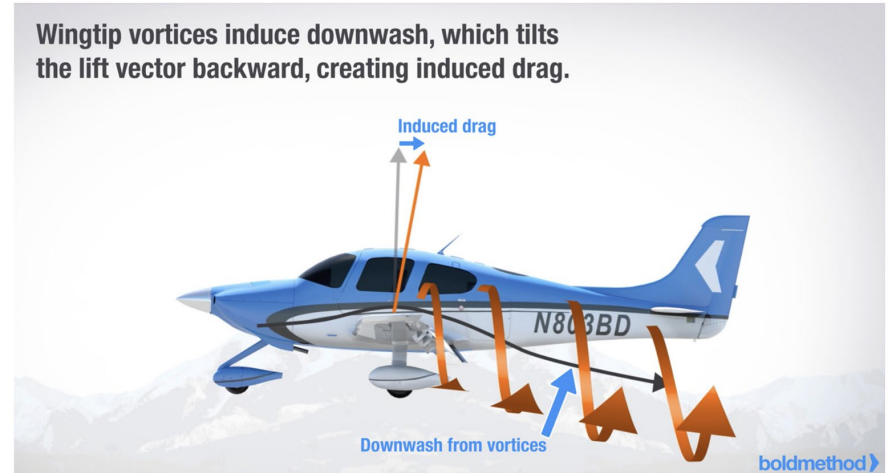
Induced Drag

The second type of drag is induced drag. In level flight, the aerodynamic properties of a wing or rotor produce a required lift, but this can be obtained only at the expense of a certain penalty. The name given to this penalty is induced drag. Induced drag is inherent whenever an airfoil is producing lift and, in fact, this type of drag is inseparable from the production of lift. Consequently, it is always present if lift is produced.



Induced Drag

Whenever an airfoil is producing lift, the pressure on the lower surface of it is greater than that on the upper surface. As a result, the air tends to flow from the high pressure area below the tip upward to the low pressure area on the upper surface. Near the tips, there is a tendency for these pressures to equalize, resulting in a lateral flow outward from the underside to the upper surface. This lateral flow imparts a rotational velocity to the air at the tips, creating vortices that trail behind the airfoil.

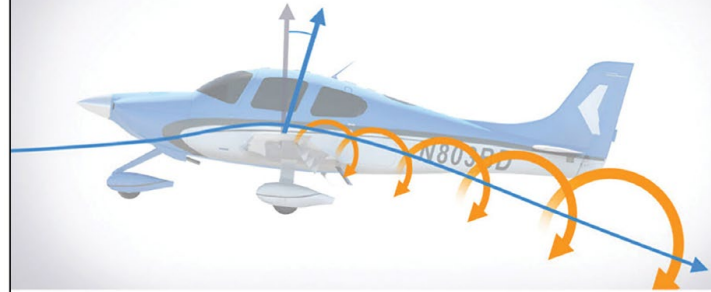


Induced Drag

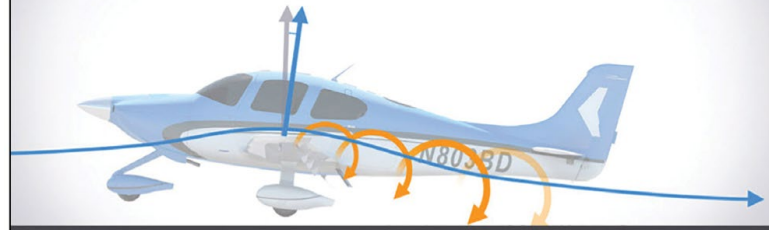
Downwash that result from the vortices points the relative wind downward, so the more downwash you have, the more your relative wind points downward. When you have less downwash, your lift vector is more vertical, opposing gravity. And when you have more downwash, your lift vector points back more, causing induced drag. On top of that, it takes energy for your wings to create downwash and vortices, and that energy creates drag.

The greater the size and strength of the vortices and consequent downwash component on the net airflow over the airfoil, the greater the induced drag effect becomes.

More Induced Drag Due To Downwash



Less Induced Drag Near The Ground





Lift/Drag Ratio

The lift-to-drag ratio (L/D) is the amount of lift generated by a wing or airfoil compared to its drag. A ratio of L/D indicates airfoil efficiency. Aircraft with higher L/D ratios are more efficient than those with lower L/D ratios. In unaccelerated flight with the lift and drag data steady, the proportions of the coefficient of lift (CL) and coefficient of drag (CD) can be calculated for specific AOA.

The L/D ratio is determined by dividing the CL by the CD, which is the same as dividing the lift equation by the drag equation as all of the variables, aside from the coefficients, cancel out.

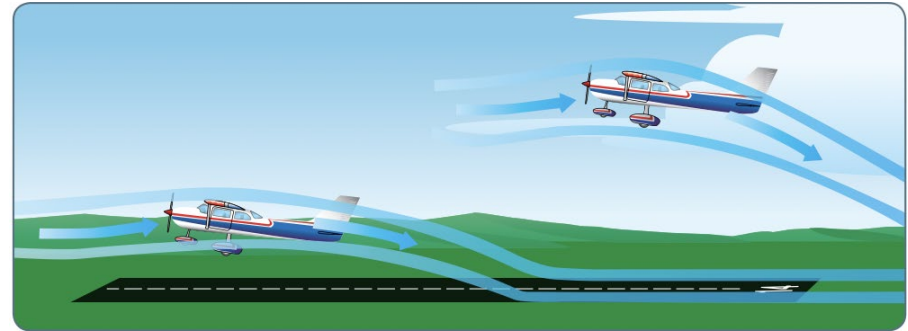
$$L = \frac{C_L \cdot \rho \cdot V^2 \cdot S}{2}$$

$$D = \frac{C_D \cdot \rho \cdot V^2 \cdot S}{2}$$

Ground Effect

Ever since the beginning of manned flight, pilots realized that just before touchdown it would suddenly feel like the aircraft did not want to go lower, and it would just want to go on and on. This is due to the air that is trapped between the wing and the landing surface, as if there were an air cushion.

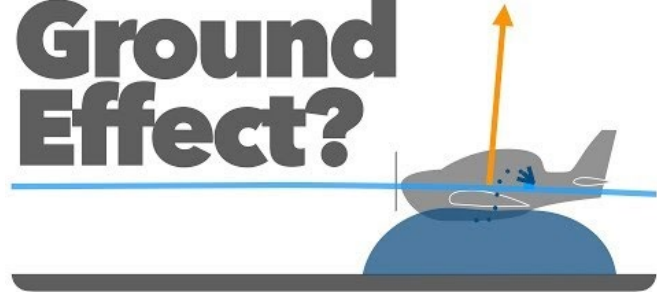
When an aircraft in flight comes within several feet of the surface, ground or water, a change occurs in the three-dimensional flow pattern around the aircraft because the vertical component of the airflow around the wing is restricted by the surface. This alters the wing's upwash, downwash, and wingtip vortices.



Ground Effect

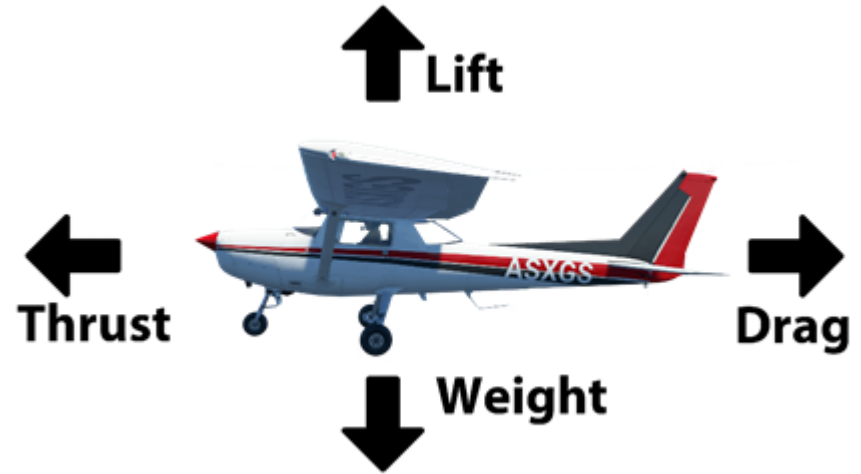
Ground effect, then, is due to the interference of the surface with the airflow patterns about the aircraft in flight. While the aerodynamic characteristics of the tail surfaces and the fuselage are altered by ground effect, the principal effects due to proximity of the ground are the changes in the aerodynamic characteristics of the wing. As the wing encounters ground effect and is maintained at a constant AOA, there is consequent reduction in the upwash, downwash, and wingtip vortices.

What is
**Ground
Effect?**



Weight

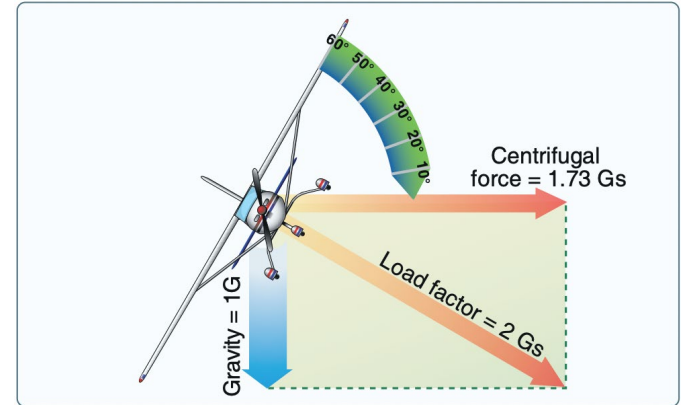
Weight has a definite relationship to lift. This relationship is simple, but important in understanding the aerodynamics of flying. Lift is the upward force on the wing acting perpendicular to the relative wind and perpendicular to the aircraft's lateral axis. Lift is required to counteract the aircraft's weight. In stabilized level flight, when the lift force is equal to the weight force, the aircraft is in a state of equilibrium and neither accelerates upward or downward. If lift becomes less than weight, the vertical speed will decrease. When lift is greater than weight, the vertical speed will increase.



Load Factor

The maximum load factor (at given bank angle) is a proportion between lift and weight. The load factor is measured in Gs (acceleration of gravity), a unit of force equal to the force exerted by gravity on a body at rest and indicates the force to which a body is subjected when it is accelerated. Any force applied to an aircraft to deflect its flight from a straight line produces a stress on its structure. The amount of this force is the load factor. While a course in aerodynamics is not a prerequisite for obtaining a pilot's license, a pilot should have a solid understanding of the forces that act on the aircraft, the advantageous use of these forces, and the operating limitations of the aircraft being flown.

For example, a load factor of 3 means the total load on an aircraft's structure is three times its weight.

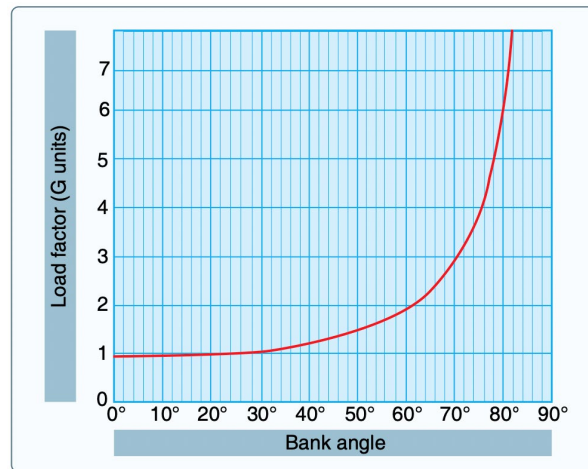


Load Factor in Steep Turns

At a constant altitude, during a coordinated turn in any aircraft, the load factor is the result of two forces: centrifugal force and weight. For any given bank angle, the Rate of Turn varies with the airspeed—the higher the speed, the slower the Rate of Turn. This compensates for added centrifugal force, allowing the load factor to remain the same.

The load factor increases at a very rapidly after a bank has reached 45° or 50°. The wing must produce lift equal to these load factors if altitude is to be maintained.

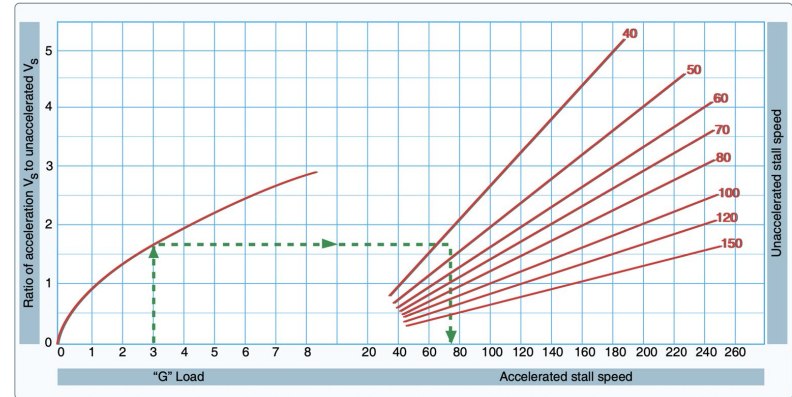
For a coordinated, constant altitude turn, the approximate maximum bank for the average general aviation aircraft is 60°. This bank and its resultant necessary power setting reach the limit of this type of aircraft.



Load Factor and Stall Speeds

Any aircraft may be stalled at any airspeed. When a sufficiently high AOA is resulted, the smooth flow of air over an airfoil breaks up and separates, producing an abrupt loss of lift, which results in a stall.

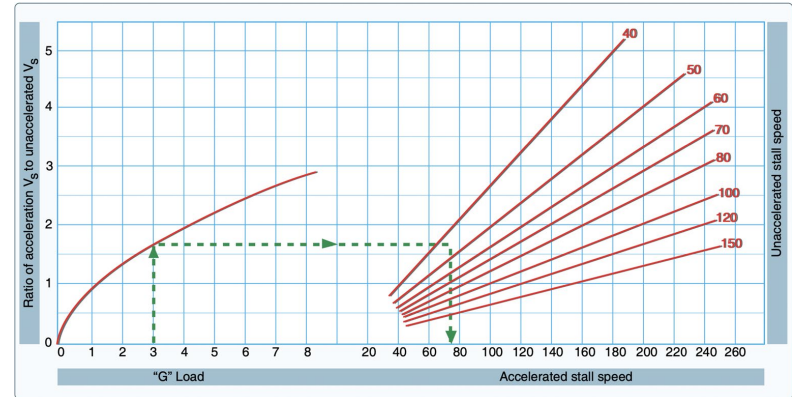
A study revealed that an aircraft's stalling speed increases in proportion to the square root of the load factor. This means that an aircraft with a stalling speed of 50 knots can be stalled at 100 knots by inducing a load factor of 4 Gs. If it were possible for this aircraft to withstand a load factor of nine, it could be stalled at a speed of 150 knots.



Load Factor and Stall Speeds

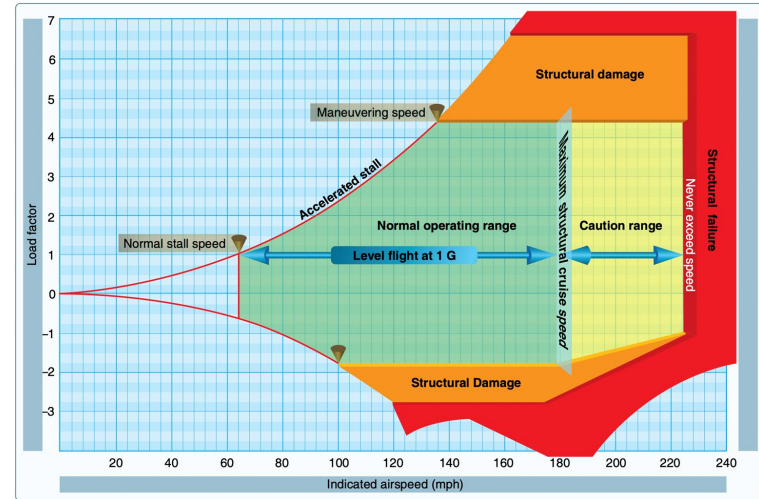
A pilot should be aware of the following:

- The danger of inadvertently stalling the aircraft by increasing the load factor, as in a steep turn or spiral;
- When intentionally stalling an aircraft above its design maneuvering speed, a large load factor is imposed.



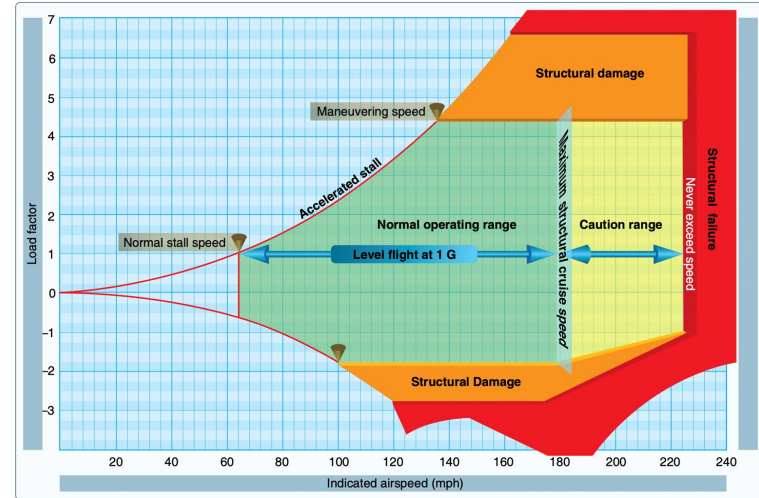
Vg Diagram

- The flight operating strength of an aircraft is presented on a graph whose vertical scale is based on load factor. The diagram is called a Vg diagram—velocity versus G loads or load factor. Each aircraft has its own Vg diagram that is valid at a certain weight and altitude.
- The lines of maximum lift capability (curved lines) are the first items of importance on the Vg diagram. The aircraft in the table is capable of developing no more than +1 G at 64 mph, the wing level stall speed of the aircraft.



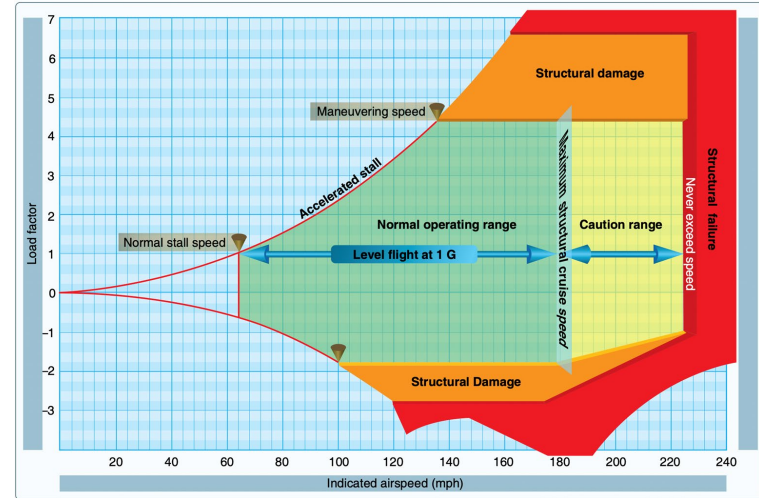
Vg Diagram

- If the aircraft is flown at a positive load factor greater than the positive limit load factor of 4.4, structural damage is possible. When the aircraft is operated in this region, objectionable permanent deformation of the primary structure may take place and a high rate of fatigue damage is incurred. Operation above the limit load factor must be avoided in normal operation.

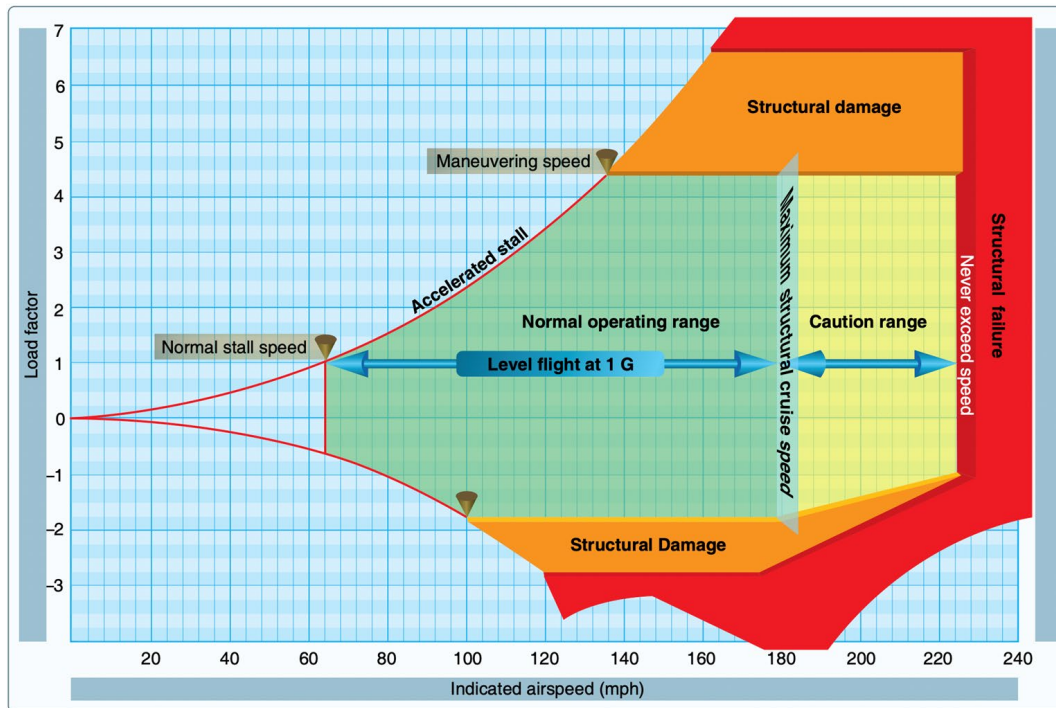


Vg Diagram

- There are two other points of importance on the Vg diagram. One point is the intersection of the positive limit load factor and the line of maximum positive lift capability. The airspeed at this point is the minimum airspeed at which the limit load can be developed aerodynamically. Any airspeed greater than this provides a positive lift capability sufficient to damage the aircraft. The usual term given to this speed is "maneuvering speed".



Vg Diagram



Vg Diagram

Another point of importance on the Vg diagram is the intersection of the negative limit load factor and line of maximum negative lift capability. Any airspeed greater than this provides a negative lift enough to damage the aircraft; any airspeed less than this does not provide negative lift capability sufficient to damage the aircraft from excessive flight loads.

The limit airspeed (or redline speed) is a design reference point for the aircraft—this aircraft is limited to 225 mph. If flight is attempted beyond the limit airspeed, structural damage or structural failure may result.



Vg Diagram

The aircraft must be operated within this “envelope” to prevent structural damage. The pilot must understand the Vg diagram and load factors for safe operation. Any maneuver, gust, or gust plus maneuver outside the structural envelope can cause structural damage and shorten the service life of the aircraft.



Boeing 777 Wing Breaks Under Load Test

