AERODYNAMICS AND PERFORMANCE

FULFILLS PA.I.F, CA.I.F, AI.II.D/AI.II.F

<table>
<tr><td colspan="2">Objective</td></tr>
<tr><td colspan="2">The student shall understand the fundamentals and principles of flight, the conditions for airplane stability, and the effects of density altitude on performance. The student shall become familiar with calculating all applicable performance figures from the POH.</td></tr>
<tr><td>Instructor Actions</td><td>Student Actions</td></tr>
<tr><td>- Explain the fundamentals of forces and free body diagrams
- Discuss methods for producing lift and thrust
- Discuss the reciprocal of each force
- Introduce the student to airplane stability about each axis, and explain coupling between axes
- Relate the effects of DA with the student’s knowledge of weather theory.</td><td>- Take notes and participate in instructor’s discussion
- Consider the design differences noted in airplanes designed for maneuverability vs training
- Consider the effects of coupling and how flying skills compensate (adverse yaw)
- Practice calculating performance values and W&B from instructor’s scenario</td></tr>
<tr><td>Case Studies</td><td>Equipment</td></tr>
<tr><td>- AOPA ASI Into Thin Air
- Pilot Induced Oscillations (PIO)
- Stinson 108-3 High DA Takeoff</td><td>- Airplane POH
- Model Airplane
- PHAK
- White Board</td></tr>
<tr><td colspan="2">Completion Standards</td></tr>
<tr><td colspan="2">The student shall explain forces in straight and level, climbing/descending, and turning flight. The student shall display proficiency in calculating performance values from the aircraft’s POH.</td></tr>
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ELEMENTS

RESOURCES

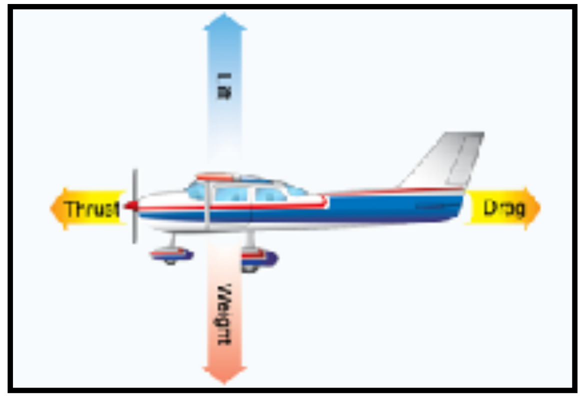
FAA-S-ACS-6C (Private Pilot ACS) - Area I Task F
FAA-S-ACS-7B (Commercial Pilot ACS) - Area II Task F
FAA-S-ACS-25 (CFI ACS) - Area III Task F

FAA-H-8083-25C PHAK Chapter 4: Principles of Flight
FAA-H-8083-25C PHAK Chapter 5: Aerodynamics of Flight
FAA-H-8083-25C PHAK Chapter 11: Weight and Balance

ERAU Principles of Flight Video

Learn to Turn

1. THE FOUR FORCES OF FLIGHT

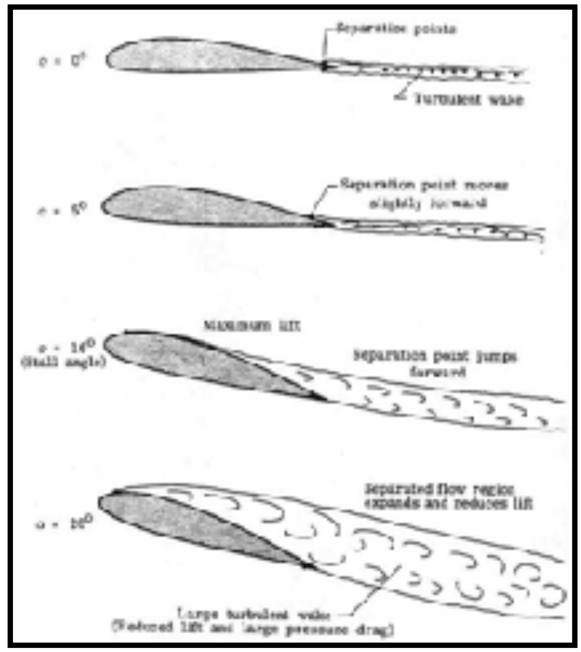


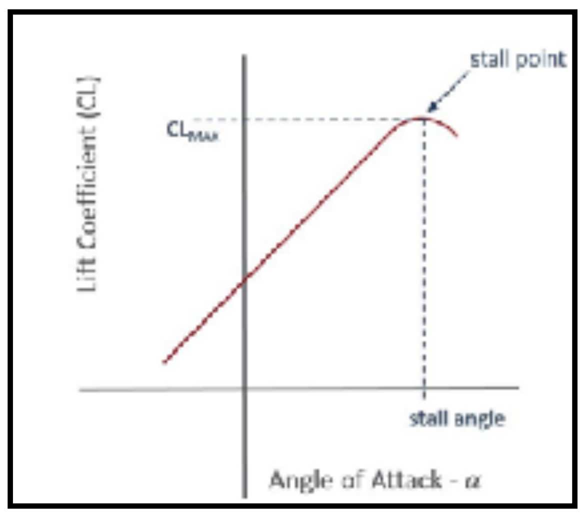
A force is a push or pull on an object. In flight, an aircraft is subject to four forces: Lift, opposing weight, and thrust, opposing drag. In steady flight (straight and level unaccelerated flight), opposing forces are equal and balance out. Lift is equal to weight, and thrust is equal to drag. This does <u>not</u> mean that all four forces are equal.

1.1. The Airfoil

Draw a wing at 0° AOA, max AOA, and slightly more than max AOA. Ask SP to identify difference.

Use the picture to define chord line and define AOA. Then introduce how the lift generated changes with AOA by showing the lift curve slope.





1.2. Lift and Weight

Weight is the simplest force to understand. The more mass inside the aircraft (fuel, cargo, people, etc), the heavier it is. This increases the weight force, and the **lift** required.

For an airplane to remain in straight and level flight, the total lift produced must equal the total weight. If the wing produced inadequate lift, there would exist a net force pulling the aircraft downward. On conventional aircraft, the wing produces a majority of this lift force, the amount of which determined by airspeed, wing geometry, and angle of attack.

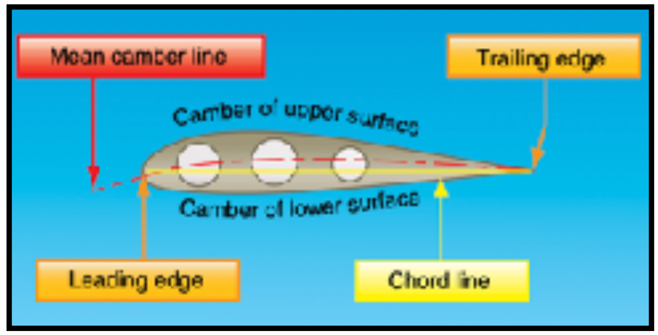


Figure 2 shows the fundamental parameters of a wing. The leading edge (front-most point on a wing) and trailing edge (aft-most point) are connected by an imaginary line known as the chord line. The mean camber line is a measure the curvature of a wing, and is defined as a curved line equidistant from the upper and lower surfaces of the wing. Typically, wings with higher camber produce more lift. A two-dimension slice of the wing, like that shown in figure 2, is referred to as the wing's airfoil.

Figure 3 Extra 300L in Inverted Flight (ref)

Asymmetric airfoils can thus produce lift at zero angle of attack due to their camber. Symmetric airfoils, even with simple profiles, can still produce significant lift but do require a positive angle of attack. This property can be useful for aircraft designed to fly inverted, like the Extra 300L in Figure 3.

All lift properties are related through the fundamental lift equation: $L = C_L \cdot q \cdot S$. S is simply the planform area of the wing, i.e. the area of the shadow it creates. The term q is a product of the airplanes velocity and local atmospheric density. C_L is the wings coefficient of lift, which changes as a function of angle of attack. The higher the angle of attack, the greater the coefficient of lift.

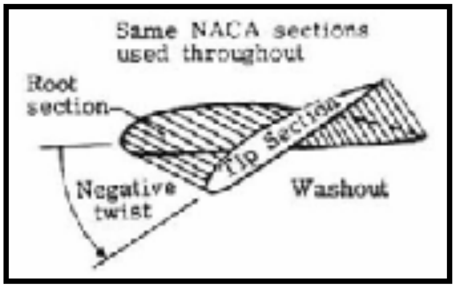
Unfortunately, there is a limit. Exceeding a certain angle attack leads to a phenomenon known as flow separation, where the airflow over the wing becomes incredibly turbulent and a severe loss of lift occurs. This is known as a stall, which is simply defined as exceeding the critical angle of attack. A typical relationship is shown in Figure x.

It is important to understand how this relates to stall speed. For a thorough explanation, see PHAK 5-25.

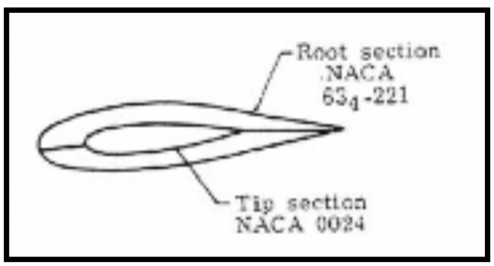
1.2.1. Methods of Delaying Stall Onset or Improving Handling Quality

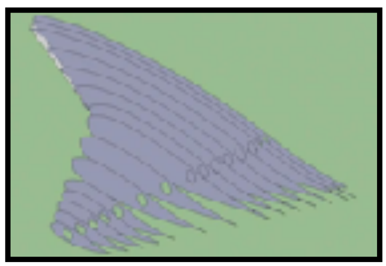
Aerodynamic and Geometric Twist

To ensure the wing root stalls before the wing tip and aileron effectiveness is preserved, the designer can choose to physically twist the wing so the root has a higher angle of attack. This is known as geometric twist or washout. In the Figure, the same airfoil is used for the entire span, but it is twisted, either gradually or bluntly, to have a lower angle of attack at the tip. The Cirrus SR-20 and SR-22 have a blunt transition for geometric twist[1]. Also, notice the negative angle at the wingtip of the F/A-18D compared to the neutral angle of incidence at the root.



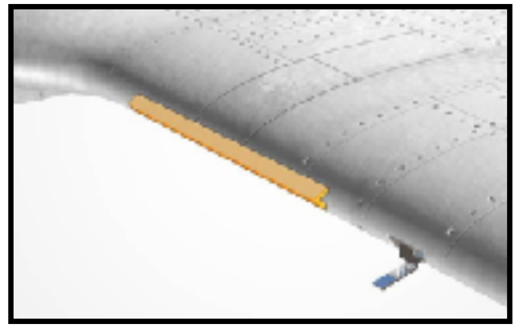
The designer could also implement aerodynamic twist, where the outbound section of the wing can gradually or bluntly transition to an entirely different airfoil. Here, the airfoil is not physically twisted, but it smoothly transitions to the airfoil marked as the "tip section." Aerodynamic twist is especially useful for flying wings and delta wings without conventional control services.





[1] Another device, known as a wing cuff, is also present here. More about these can be found at FlyingMag and Wikipedia

Stall Strips



Stall strips are small wedge shaped strips attached the the leading edge of a wing, designed to induce flow separation before the wing reaches its critical angle of attack. Check out this Boldmethod reference. While these strips are typically placed on the inboard section, they can sometimes be inboard and outboard, like in the case of the Piper PA-38 Tomahawk. Piper's reasoning is to reduce the roll rate during stalls.

Vortex Generators

Methods to delay flow separation exist, not so much for improving safety, but rather to promote low-speed handling characteristics. This Boldmethod, AOPA, and Stack Exchange reference dive into the specifics on how these small devices energize the boundary layer.

Vortilons

An in-depth analysis by NASA can be found here.

Wing Fences

Wing fences are barriers on the wing's upper surface to inhibit spanwise flow, predominately installed on swept-wing aircraft. They improve the stall characteristics and reduce drag in transonic flight.

1.3. Thrust and Drag

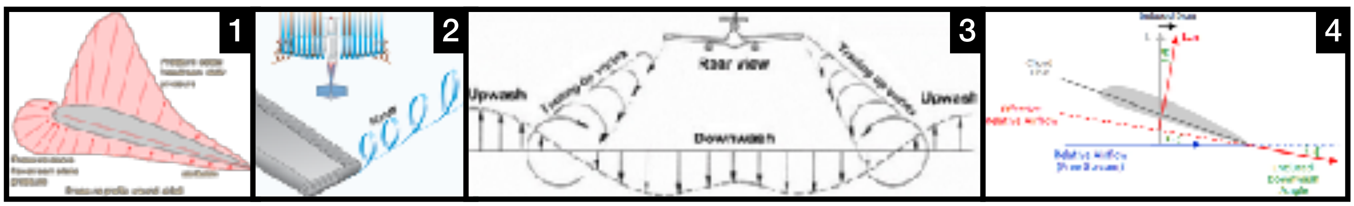
Thrust provides the forward force to propel an aircraft against drag, which is typically either a propeller or jet engine. Trust is measured as a force (pounds). Power is also often used to characterize the performance of piston engines, calculated from the aircraft's thrust multiplied by velocity, with units of horsepower. A typically relationship between thrust and power with velocity is shown below in section .

1.3.1. Induced Drag

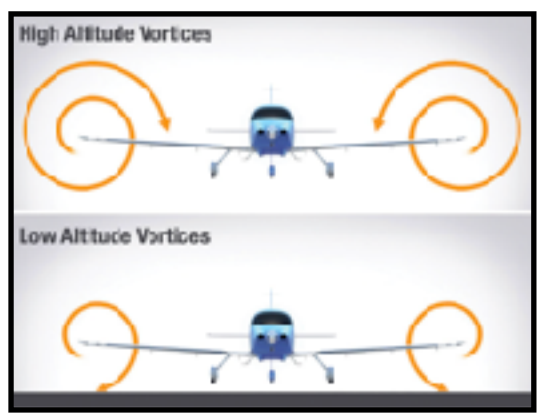
Lift is, by definition, the force exerted on an aircrafts wing due to pressure differences between the upper and lower surface. Thus, whenever an aircraft is producing lift, the lower surface as a higher than ambient pressure, and the upper surface has a lower than ambient pressure, as seen in Figure 5.

The air curls around the wingtips and creates spiraling vortices behind the wing, as well as a significant spanwise flow component that is inward on the upper surface and outward on the lower surface (see wing fences). These trailing vortices are not only incredibly strong, prompting a section in AIM 7-4 and an Advisory Circular (AC 90-23G), but also create downwash behind the wing.

The trailing edge downwash is accompanied by a leading edge upwash, which functions to angle the relative wind. Since lift is perpendicular to the relative wind, there is now a portion of lift pulling the wing backwards. The create the pressure difference, the stronger the vortices, and the more induced drag created. Thus arises the common saying, “heavy, clean, and slow” creates the strongest wake turbulence.



1. Lift production is preceded by a pressure differential
2. Pressure differential creates vortex motion, vortex motion induces spanwise flow along entire wing, creating a line of vortices behind the wing
3. Downwash is produced behind the entire wing
4. Relative wind is titled and induced drag is created



At low altitudes, the wingtip vortices are physically restricted by the ground. The net downwash is reduced and induced drag is weakened.

It is important to note that vortices are not the only mechanism to induce downwash. While vortices are minimized on higher aspect-ratio wings and eliminated on infinitely long wings, some downwash is still present due to the effects of Newtons 3rd Law.

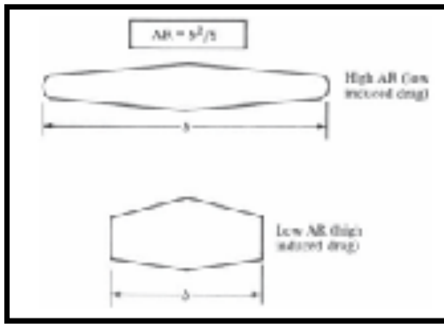
Wake Turbulence Avoidance

Pilots should read AIM 7-4-4 and AC 90-23G Section 8 at a minimum to familiarize themselves with pertinent wake turbulence avoidance procedures.

Methods for Reducing Induced Drag

A theoretical wing of infinite length has no wingtips, which then cannot have vortices. These wings are said to have no induced drag. High aspect ratio wings, like those on gliders, nearly achieves an infinite wing effect and have low coefficients of induced drag.

A wing that minimizes the pressure differential near the wingtips minimizes the strength of the vortices. The optimal planform however, an elliptical wing, still remains less effective than increasing the aspect ratio.



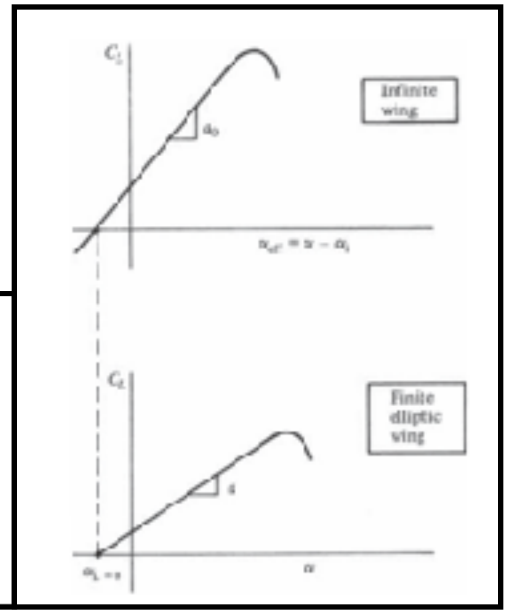


Figure 8 Effects of AR on $C_{D,i}$

Figure 9 Various Wing Planforms
Left – F104 with AR = 2.45
Middle – Schleicher ASK-21 with AR = 16
Right – Supermarine Spitfire with elliptical planform

1.3.2. Parasite Drag

Parasite drag is all drag not associated with the production of lift. In engineering terms, it refers to the viscous effects of air acting on the airplane. Parasite drag includes form drag, interference drag, skin friction drag, and wave drag.

Form Drag

Form drag is associated with "how aerodynamic does it look?" An object with blunt edges and many protrusions produces more turbulent flow than a streamlined profile. Many exterior features of an aircraft are designed to minimize form drag, as seen in Figure 10.

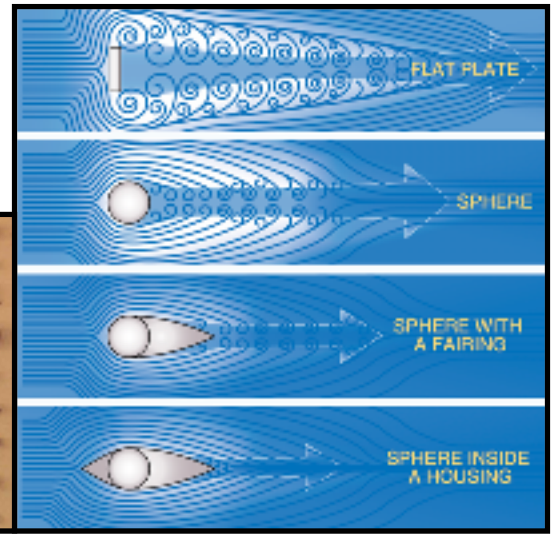


Figure 10 Form Drag
Left – Wheel pants on Jabiru
Middle – Bracing wire for biplanes. Note the non-circular cross section. Circular cables can contribute up to 50% of airframe drag!

Interference Drag

Sharp edges in the streamwise direction force streamlines together and create turbulent flow. Of course, this results in drag. This Long-EZ owner modified the existing wingtip rudder, originally mounted with no fairing, to a blended wingtip with a smooth transition from horizontal to vertical. Here is another video about CFD and flight test analysis on blended wingtips vs stock wingtips. Additionally, many joined edges have fairings to minimize interference drag.

Figure 11 Interference Drag Minimization
Left – Cessna 172S Strut Fairing
Right – Long-EZ Wingtip Rudders

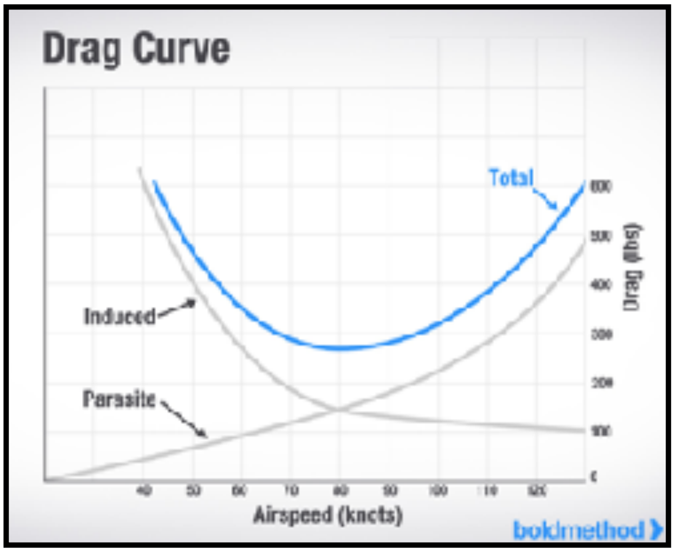
Skin Friction Drag

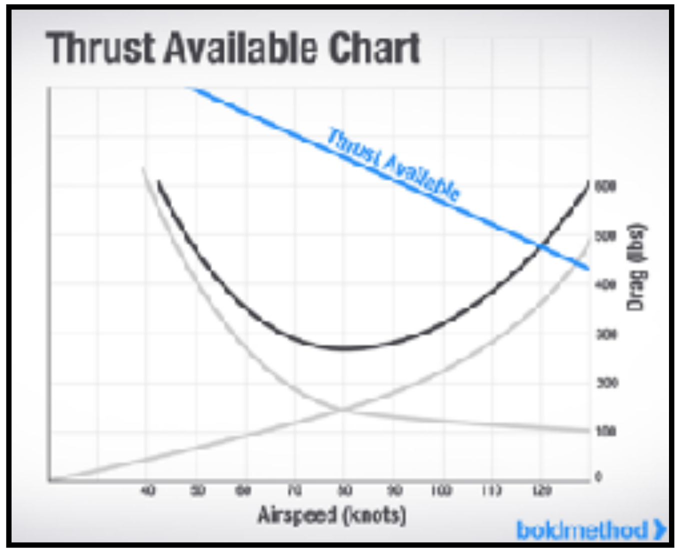
At a microscopic level, the surface of an airplane is incredibly rough. Even though air is not solid, it still exerts a force on the surface and creates drag.

1.4. Performance Parameters

1.4.1. Climb Performance

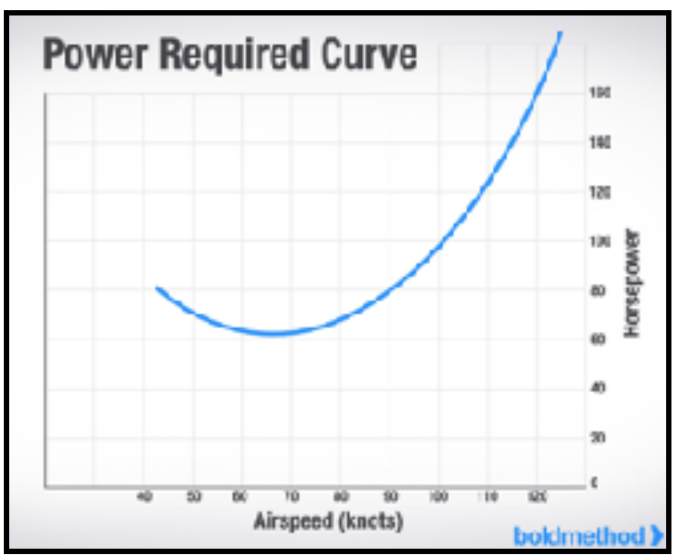
Since thrust opposes drag, it is useful to overlay a piston engine's thrust available chart to depict the difference between thrust available and thrust required (drag). When thrust required is greater than thrust available on the high end of airspeed, the airplane can no longer accelerate, even at full throttle. The low end of airspeed is typically predominated by stall rather than thrust requirements.

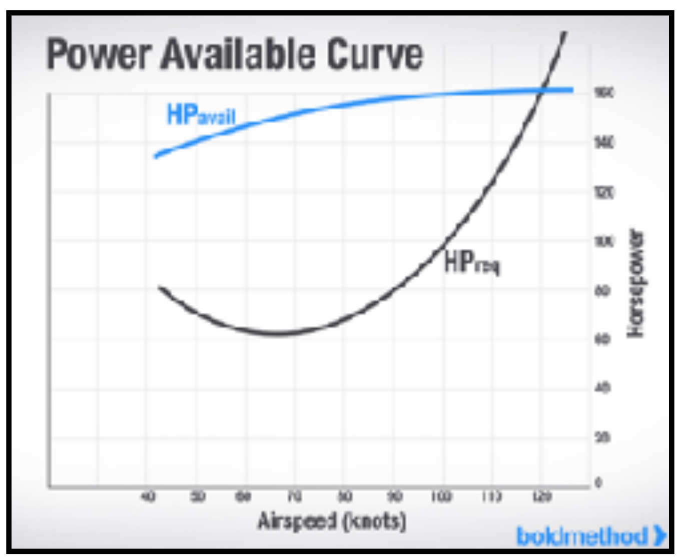




The maximum distance between total drag and thrust required yields the speed for maximum angle of climb, Vx.

Multiplying each point along this graph by the corresponding airspeed yields power required. The maximum distance between power required and power available yields the speed for maximum rate of climb, Vy.





1.4.2. Cruise Performance

Cruise performance is predominantly influenced by airframe drag. Will an aircraft could have excellent climb performance from excess power available during slower airspeeds, as an aircraft accelerates, the total drag increases with v^2.

2. PROPELLER EFFECTS

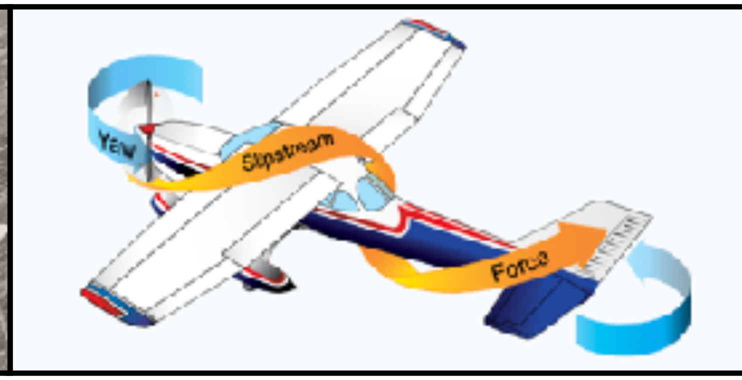
The PHAK does an excellent job of explaining propellor configurations, designs, and left turning tendencies. However, left turning tendencies will be reviewed here.

Torque

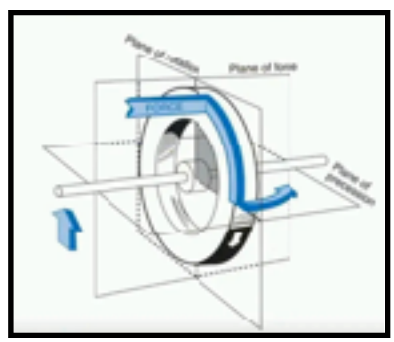
Newton's third law is not limited to translational motion; rotation is subject to the same "every reaction has an equal and opposite reaction" principle. As the engine spins the propellor with a certain amount of torque, the airframe wants to rotate in the opposite direction. This is extremely noticeable on the ground, where the left tire bears more weight and thus more friction, than the right tire.

Corkscrew/Slipstream

The propellor induces a spiraling rotation in airflow around the airplane, which can sometimes be visible. The slipstream impinges upon the left side of the vertical tail, inducing a left yaw.

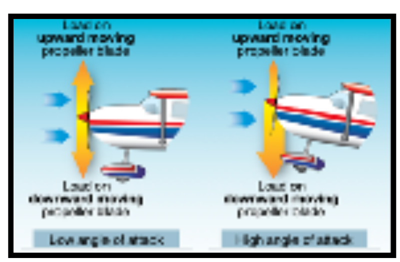


Gyroscopic Precession



The propellor, essentially a heavy, spinning disk, inherits the same properties as any other gyroscope. Any attempts to alter the plane of rotation of a gyroscope is subject to the effects of gyroscopic precession, where the force applied results 90° ahead in the direction of rotation. Gyroscopic precession is most prominent in tailwheel aircraft when the lift the tail for takeoff. However, any pitch or yaw changes will induce gyroscopic precession.

P-Factor



Imagine a helicopter flying forward with a known airspeed. One side of the rotor is spinning toward oncoming air (the advancing blade), and the other side is spinning away from oncoming air (the retreating blade). As a result, there is a lift imbalance in the rotor.

The same principle applies with airplane propellors in slight climb attitudes. The downward moving blade has a small but non-negligible forward component, which induces a large forward force on the right side of the blade disc.

3. LOAD FACTOR

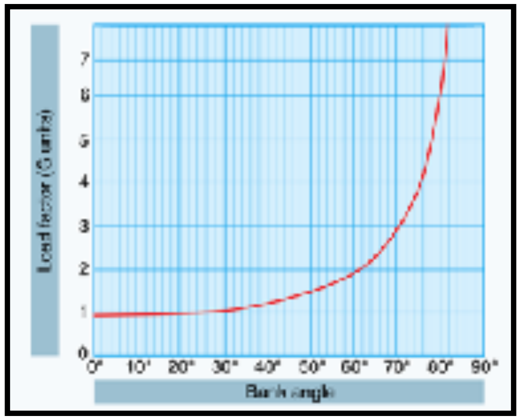
Suppose an airplane is parked on the ramp. The airplane is not accelerating, so we say the total load on the airframe is 1g, or one times the force of gravity. Imagine the same airplane was flying straight and level. Even though it is suspended in the air, it still is experiencing 1g because it remains in unaccelerated flight.

The pilot decides to demonstrate a steep dive followed by a rapid pull-up. Even though the airspeed may remain constant, the pilot is accelerating by changing the direction of flight. Thus, the load factor (symbolized by ‘g’ or ’n’) on the airplane increases according to magnitude of acceleration. The airplanes POH outlines load factor limitations in section 2.

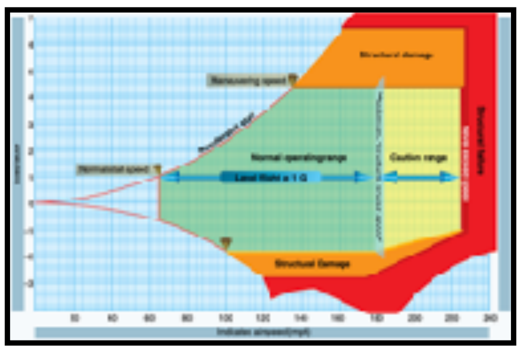
2.17 FLIGHT MANEUVERING LOAD FACTORS

	Normal	Utility
(a) Positive Load Factor (Maximum)		
(1) Flaps Up	3.8 G	4.4 G
(2) Flaps Down	2.0 G	2.0 G
(b) Negative Load Factor (Maximum)	No inverted maneuvers approved.	

Load factor also increases in turning flight, as even though the airplane may hold a constant airspeed, its direction changes. The relationship between bank angle and load factor is shown in Figure x. As seen in the figure load factor increases rapidly after ~60° of bank.



Stall speed is proportional to the square root of the load factor. For example, a 75° bank will impose a 4G load factor which will double the stalling speed. As a result, an airplane can be stalled at <u>any airspeed</u>, although at the same critical angle of attack. The wing delivers the force needed to achieve a certain accelerating in the form of excess lift. So, to achieve the required amount of lift, the angle of attack is increased, bringing the airplane closer to the critical angle of attack. For example, the rapid pull-up may increase the angle of attack to nearly $C_{L_{max}}$. Combined with a high enough speed, the wing may produce so much lift that structural damage occurs.



The Vn or Vg diagram depicts the flight envelope graphically. Let’s start with the maneuvering speed (Va). At airspeeds below Va, a full scale control deflection is insufficient to cause structural damage or failure. While the airplane may achieve $C_{L_{max}}$, the total lift product at these speeds keeps the airplane below the max allowable load factor. However, above Va, the total lift product may exceed the load factor prescribed in the POH, and structural damage or failure may occur depending on the airspeed. The right side of the green range is known as maximum structural cruising speed, or Vno (**n**ormal **o**perating). At higher airspeeds, gusts and turbulence may momentarily cause the airplane to exceed its limit load factor. At even higher airspeeds, airspeed alone may produce sufficient loads to cause failure. The left side of the diagram is limited by stall speed. At 1g level fight, the stall speed is identical to Vs. However, when operating at less than 1g, stall speed actually decreases, and at 0g, the airplane cannot be stalled! The wing is not producing any lift, which can only happen at a C_L of 0 for a nonzero velocity.

4. AIRPLANE STABILITY AND CONTROL

> The flying qualities of a particular airplane cannot be discussed unless the total mission of the airplane and the multitude of individual tasks associated with that total mission are defined.

– U.S. Naval Test Pilot School Flight Test Manual

Every airplane fulfills a different task. A Cessna 172, while a fantastic trainer, is a poor high-speed research platform. Conversely, student pilots may wish to acquire experience before conducting their first solo in a North America X-15.

Stability refers to how an airplane responds to a disturbance such as wind gusts and control inputs. Does it have an initial tendency to return back to its original flight path? Does it completely depart controlled flight?

Controllability and stability are often discordant in the design process. An airplane should be controllable, so that the pilot can have adequate maneuverability during high-precision tasks ranging from landing to aerial refueling. If an airplane is too stable, it will be difficult to control for these high precision tasks, although easier to control in other phases of fight, like cruise. The less stable an airplane is, the more time the pilot must devote to simply controlling the airplane.

4.1. Static Stability

Static stability refers to the <u>initial</u> tendency to return to equilibrium. Like the following figure of a ball in a hill on valley, an airplane that returns to its original state is statically stable, and an airplane that has an unbounded departure from controlled flight is statically unstable. An airplane that finds equilibrium in its new position is neutrally stable.

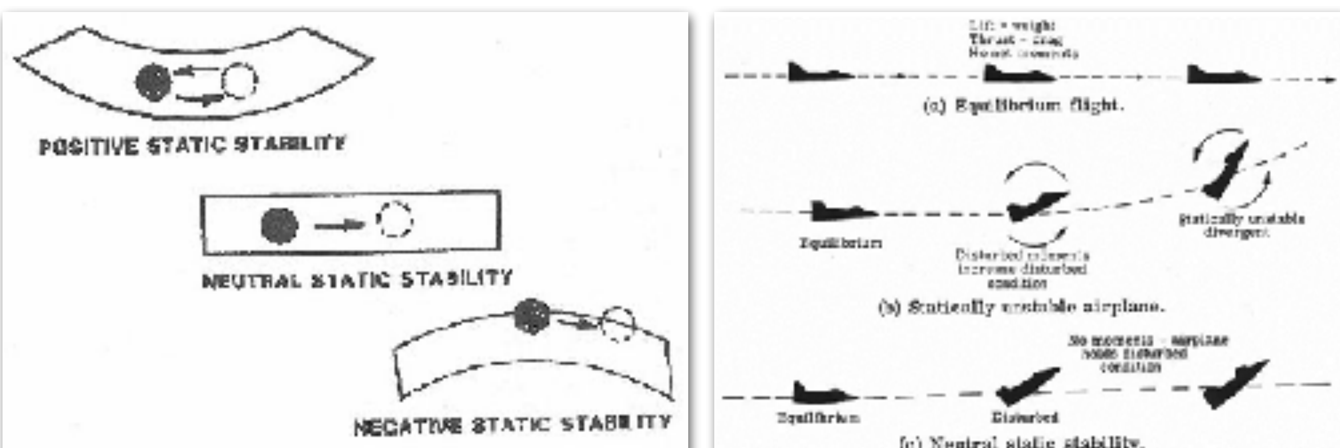


Figure 12 Static Stability

4.2. Dynamic Stability

Dynamic stability refers to the airplanes transient response toward a disturbance. For the statically stable case (see the ball in figure 12), the ball will roll back and forth a few times before coming to rest. The ball is statically stable, since it possesses a tendency to return to equilibrium, and dynamically stable, since the magnitude of the oscillations decreases. This is known as damped motion.

Motion may be dynamically unstable. For example, wing flutter repeatedly passes through equilibrium, but at high enough speeds may grow in amplitude until structural failure. Check out this wind tunnel video, glider video, and PA-30 video.

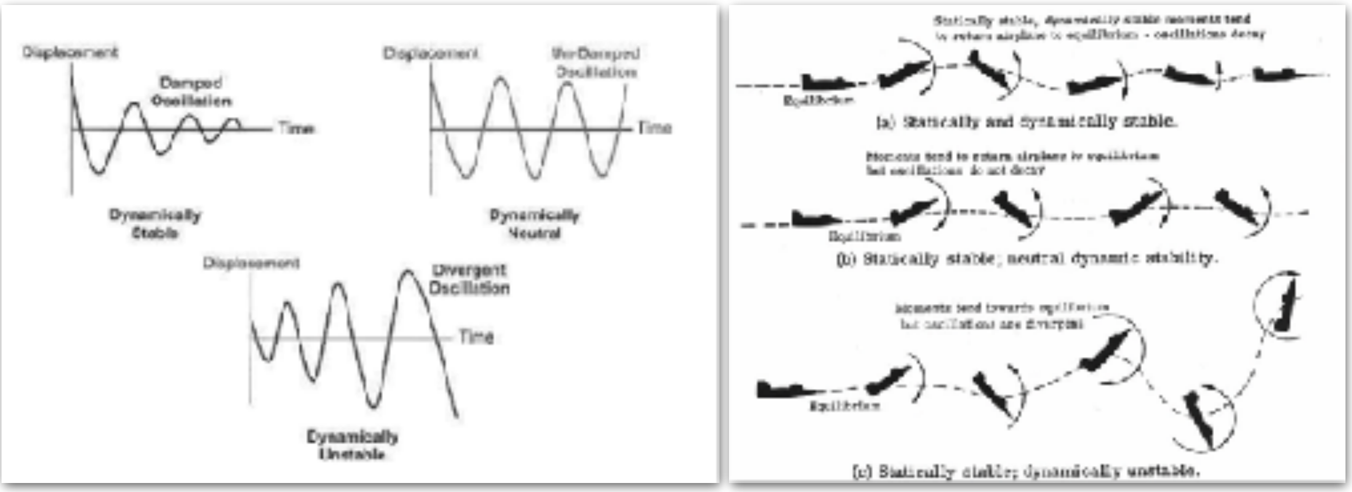


Figure 13 Dynamic Stability

4.3. Longitudinal Stability

Longitudinal stability refers to both static and dynamic stability about the longitudinal (pitch) axis. The most important parameter in longitudinal stability is the relationship between pitching moment and lift coefficient or angle of attack.

If an airplane is disturbed to a nose-up attitude from level flight, it should possess a nose down pitching moment. The opposite is true for a nose-down disturbance. Typically, the main stabilizer is the horizontal tail. The relationship between pitching moment and angle of attack is known as C_{m_α}. An airplane flying with only the wing/fuselage will not be stable.[2]

The wing/tail balance is imperative to maintain airplane stability. Typically, the CG is located in front of the center of lift, although in extreme cases the CG can be slightly behind considering wing moments. As the CG moves rearward C_{m_α} decreases until there is no longer a pitching moment associated with a change in angle of attack, resulting in neutral static stability. Any further rearward movement of the CG yields a

[2] Flying wing designs incorporate aerodynamic exploits like reflexed airfoils and aerodynamic twisting

reverse in C_{m_α} and then airplane becomes unstable. This longitudinal position of the CG is known as the neutral point and defines the aft CG limit. See this tool from Boldmethod to see the influence of CG on loading.

As the CG moves forward, the airplane feels more "nose heavy" and requires more nose up elevator. The elevator control power, $C_{m_{\delta_e}}$, is the limiting factor in determining the forward CG limit.

There are two modes of longitudinal dynamic motion: phugoid and short period. Most pilots intuitively understand the phugoid mode, where airspeed and altitude are traded at constant angle of attack. By pushing the nose down, the airplane will begin accelerating, until sufficient lift causes the airplane to enter a climb with decreasing airspeed. At the top of the cycle, the airspeed is sufficiently low to induce a descent. The cycle continues for a few cycles and then damps. The period is quite long and the motion is quite benign to not be dangerous. The short period mode is much quicker and heavily damped, so it will be omitted.

Longitudinal motion is unique in that is in uncoupled, that is it is independent of roll or sideslip.

4.4. Lateral Stability

There is no aerodynamic mechanism to produce a restoring force or moment for a lateral (roll) disturbance unless a sideslip develops! However, a sideslip will nearly always develop in the direction of the roll due to the weight now having a lateral component. For example, a right bank disturbance will induce a right sideslip and a left bank induces a left sideslip. This relationship is known as C_{l_β}, where l is the restoring rolling moment and β the sideslip angle, and the phenomenon is known as the dihedral effect.[3] Four aerodynamic modes influence the magnitude of the dihedral effect

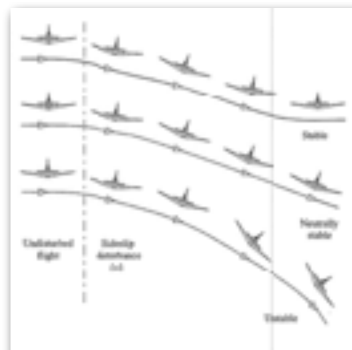


Figure 14 Lateral Stability

Interference Effects

Wing placement on the fuselage can have the same effect as a significant dihedral angle.

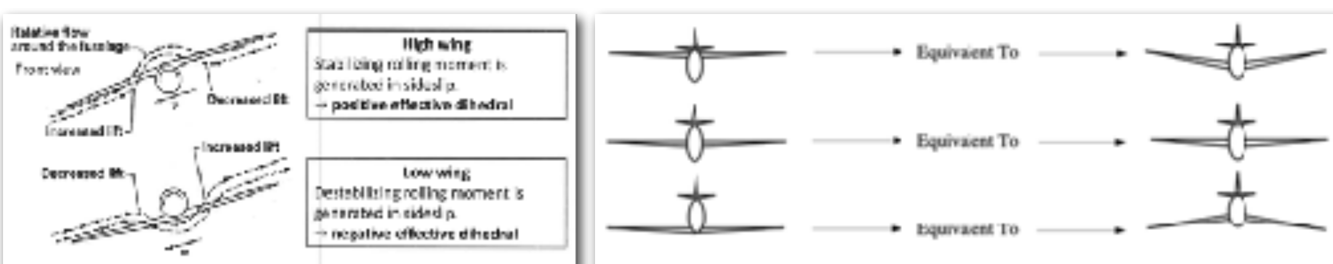


Figure 14 Wing Placement Effect

[3] Not to be confused with wing dihedral, which is a contributor to the dihedral effect!

Wing Dihedral Angle

Wing dihedral is the upward angle of the wings. In a sideslip, the lower wing has a higher angle of attack than the upper wing, inducing a rolling moment. Positive dihedral increases the lateral stability, while negative dihedral decreases the lateral stability. Many high-wing transport aircraft have so much lateral stability, they need a mechanism decrease C_{l_β}.

Figure 14 Wing Dihedral
Left – AN-225 showing significant anhedral
Right – Model showing higher angle of attack on lower wing with dihedral

Wing Sweep

> Wing sweepback tends to contribute to positive dihedral effect since the forward wing's effective sweep angle is reduced and the trailing wing's effective sweep angle is increased.

– USNTPS 103 5.2.1.3.1

Forward sweep will decrease the dihedral effect component.

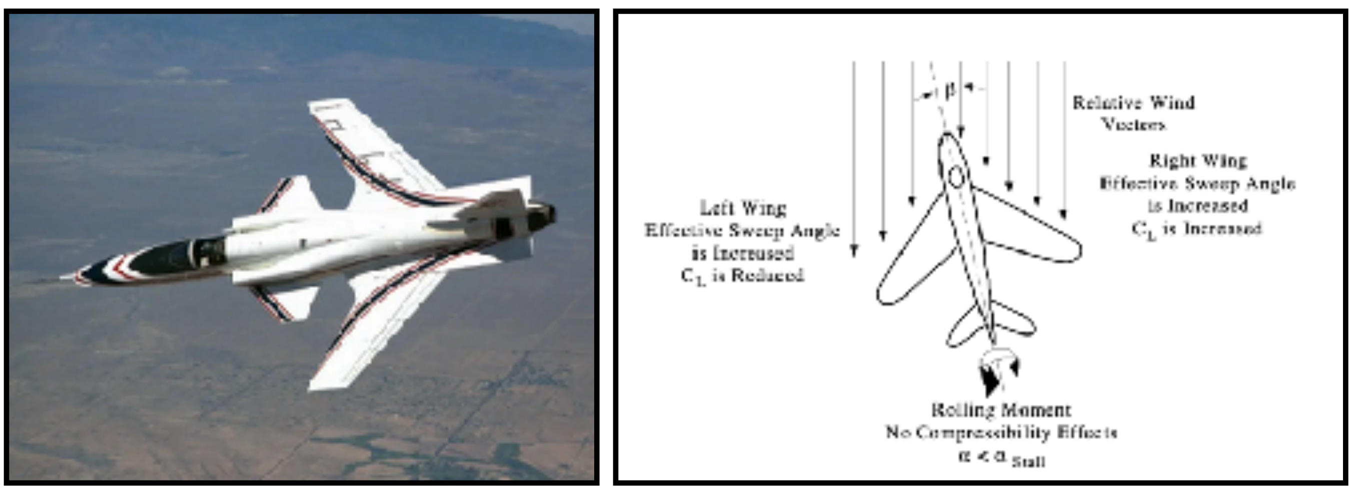


Figure 15 Wing Sweep

Keel Effect / Vertical Tail Placement

The surface area above or below the longitudinal axis along the airplanes side influences the roll moment developed in a side slip. Having more surface area above is stabilizing, since the aircraft wants to bank away from the sideslip, while having more surface area below causes the aircraft to roll into the sideslip. Some aircraft have fins or vertical tails on the bottom of the fuselage to weaken the lateral stability.

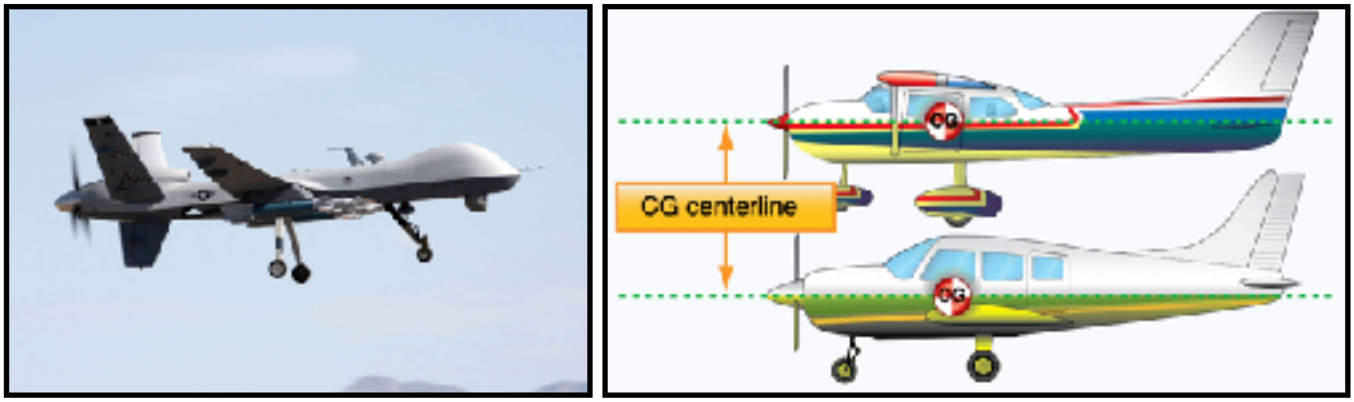
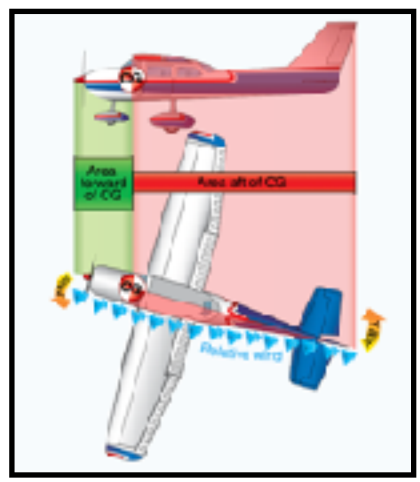


Figure 15 Vertical Tail Placement
Left – General Atomics MQ-9 Reaper with ventral fin

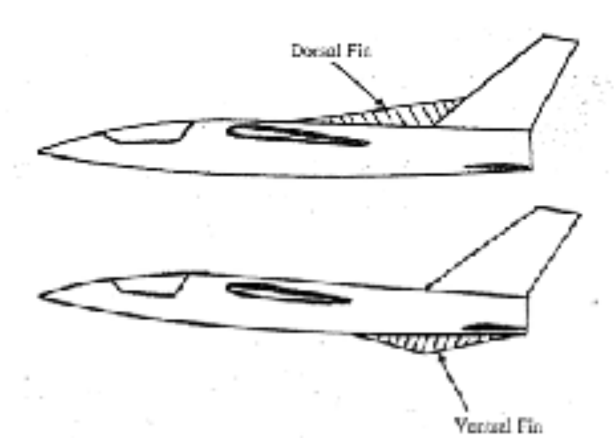
4.5. Directional Stability



Directional stability, similar to lateral stability, is driven as a result of an induced sideslip. While the fuselage and vertical tail are the primary contributors, the wing shape too has an effect, although a non-swept and non-dihedraled wing has no contribution.

Fuselage and Fin Contribution

The fuselage contribution is contrasted to the lateral stability case, where instead of area above/below the longitudinal axis of interest, area in front and behind the vertical axis is of interest. In any amount of sideslip, the fuselage has a natural tendency to weathervane into the relative wind and counter the sideslip. Designers may add a ventral fin underneath the fuselage or a dorsal fin typically as a vertical tail extension above the fuselage, depending on the desired lateral stability repercussions.



4.6. Lateral Directional Coupled Motion

Lateral and directional motion are inherently coupled together. Adverse yaw occurs on airplanes with a conventional aileron configuration. The downward moving aileron creates excess lift, which induces additional drag. The airplane is yawed in the opposite direction of the bank. Methods to minimize this phenomenon are detailed in 1.Ga, Airplane Flight Controls.

The Dutch Roll motion can be excited with a sudden rudder input. The outer wing moves faster than the inner wing, creating more lift, inducing a bank. The increase in lift is associated with an increase in drag, including a yaw in the opposite direction. The other wing now moves faster, and the cycle continues as seen in this video.

5. WEIGHT AND BALANCE

As discussed in the Airplane Stability and Control section, proper placement of the center of gravity is imperative for stability. Too aft and the airplane will suffer pitch attitude departures, and too forward the pilot will be unable to rotate on takeoff, or too heavy and the airplanes structure will deform under the weight.

Every airplane is required to carry onboard a weight and balance sheet, as seen in Figure x. The empty weight CG is calculating as a length relative to a known datum point, which here is 66.25 in ahead of the wings leading edge, per the POH.

Any weight loaded behind this CG moves the net CG aft, and any weight loaded in front of the CG moves the net CF forward. The airplane is like a see-saw, except instead of having to balance about one particular point, there is a small range of allowable CG.

Pilots should calculate the center of gravity and gross weight before every flight to ensure they are within limits, as outlined in Section 6 of the airplane's POH. Most weight and balance forms look similar to the one below, so that will be used in this example. Consider the loading in this example:

*Values from POH and W&B	**Weight [lbs]**	**Arm [in]**	**Moment [lb in]**
Basic Empty Weight	1171 lbs	74 in	86643
Pilot			
Passenger			
Fuel		75.4	
Baggage		115	
Total			

Pilot	130 lbs
Passenger	150 lbs
Fuel	30 gal / 180 lbs
Baggage	10 lbs

Let's start with the pilot and passenger. Their weights are known, and the POH includes a table to convert seat position to moment arm. Fuel quantity and arm are known, and an easy 6 pounds per gallon converts this quantity into weight. Baggage weight and arm are known as well.

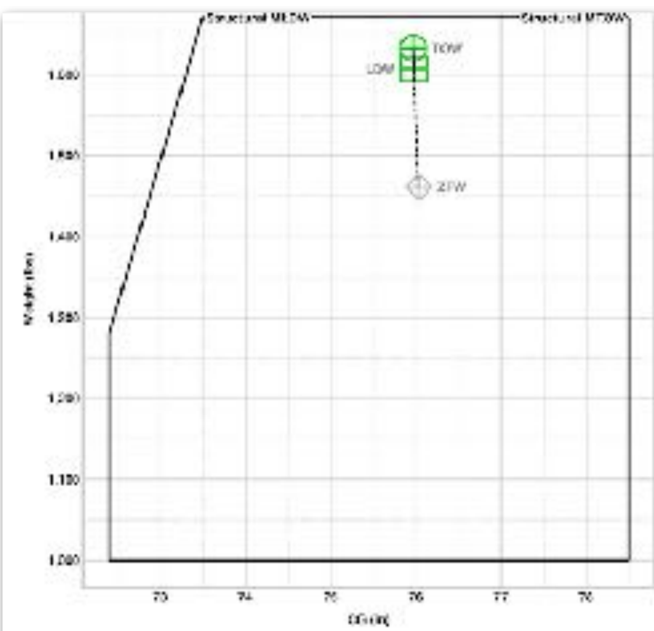
Moment is simply the product of weight and arm, analogous to torque. The further away a weight is from the center of our fictitious see-saw, the greater the contribution. Each weight in our table has an associated moment arm that should be summed for a final moment arm.

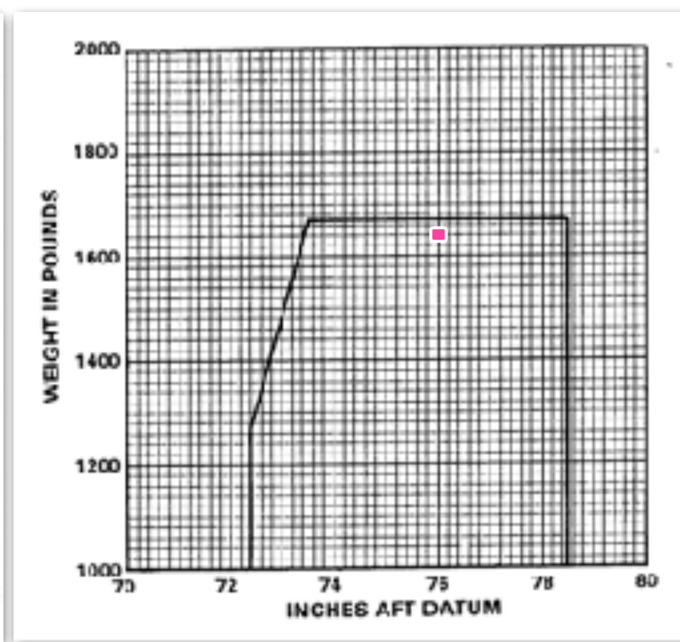
	Weight [lbs]	Arm [in]	Moment [lb in]
Basic Empty Weight	1171	74	86643
Pilot	130	82.3	10699
Passenger	150	83.9	12585
Fuel	180	75.4	13572
Baggage	10	115	1150
Total	**1641**	**75.96**	**124649**

Seat Position	Arm [in]
FWD 1	80.8
2	82.3
3	83.9
4	85.5
5	87.5
AFT 6	89.5

Once all the weights and moments are summed, we can divide the total moment by total weight to get ramp CG location. This POH does not include a taxi/runup fuel burn, which may be important in some aircraft that have different takeoff weight limits.

The allowable range of weight and CG is shown in the figure to the right. Our airplanes's configuration is inside the envelope! This same process can be done in ForeFlight using their weight and balance tool and the Tomahawk profile. The ForeFlight envelope will also depict fuel burn changes in the CG.





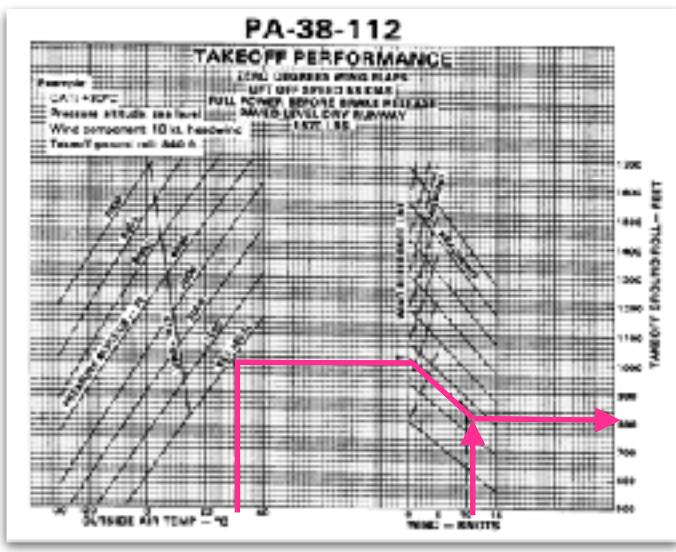
6. ATMOSPHERIC EFFECTS ON PERFORMANCE

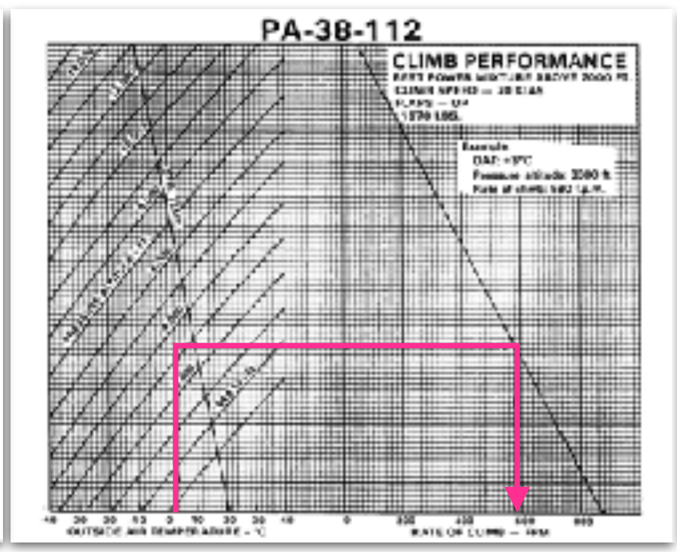
Pressure altitude is the theoretical altitude the airplane's ambient pressure would be found on a standard day, i.e. 1" Hg per 1000ft of altitude. This is known as the height above the standard datum plane.

A more useful value in calculating airplane performance is density altitude, which is the airplane's ambient density is found. Density altitude is pressure altitude corrected for nonstandard temperature.

Higher density altitudes decrease the performance of airplanes, as there is physically less air for combustion, less air for the propellor to push against, and less air for the wings to generate lift. Factors in causing high DA are known as the 3 H's: Hot, High, Humid (as moist air is less dense than dry air). Longer takeoff and landing distances and decreased climb performance are the greatest dangers of high DA operations. This video shows a Stinson 108-3 crash after it failed to climb after takeoff due to a high DA.

Aircraft POH include tables on takeoff and landing distances and climb performance, and many weather services and AWOS sites clearly state the density altitude. For takeoff distance, simply find OAT and draw a line to pressure altitude, then over to the wind reference line. Follow the headwind or tailwind correction line until the wind component, then draw a line to takeoff ground roll. More takeoff performance charts exists for 21° flap configurations and short field conditions. Similar charts exists for landing performance. Each chart has example conditions which are highlighted in pink.





While selecting a cruise altitude, it is important for the pilot to consider not only weather, but also if the altitude is obtainable. However, there are numerous cruise performance charts for the pilot to reference.