DOCUMENT
GSM-G-CPL.002

DOCUMENT TITLE
AERODYNAMICS 1

CHAPTER 5 – STALLING

Version 1.0
September 2012

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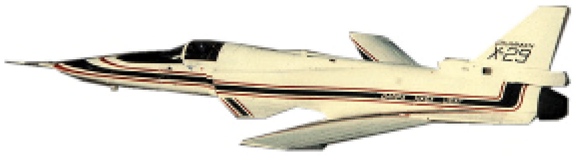
THE STALL

INTRODUCTION

An aircraft needs to produce lift to maintain straight and level flight, which is created by the aircraft moving through the air under the power of some type of engine.

If the engine power is lost, the aircraft will eventually start to descend due to the fact that not enough lift is being produced.

This is known as the **Stall,** and a close examination of this condition will now take place.



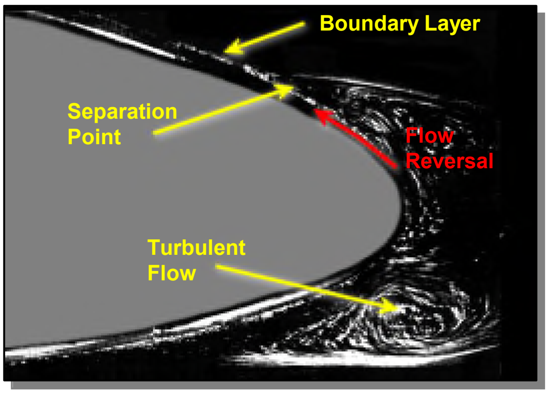
X-29 Experimental Aircraft – able to fly at high angles of attack without stalling

BOUNDARY LAYER SEPARATION

On an aircraft wing, there is a continual reduction of Boundary Layer energy as flow continues aft on a surface.

This is due to two reasons:

- Surface Friction
- Adverse Pressure Gradient



The adverse pressure gradient decreases the energy of the boundary layer, which stagnates.

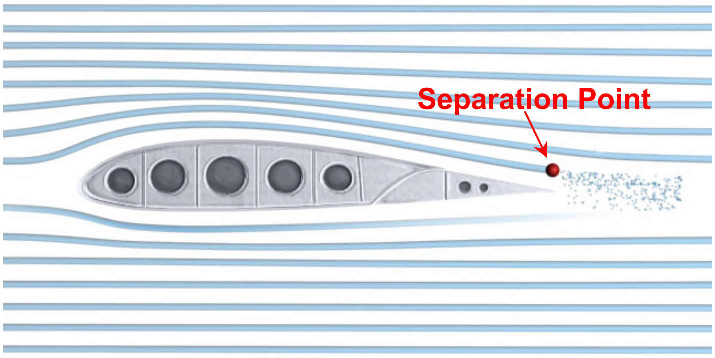
The airflow is unable to stay attached to the surface and separates (***Separation Point***).

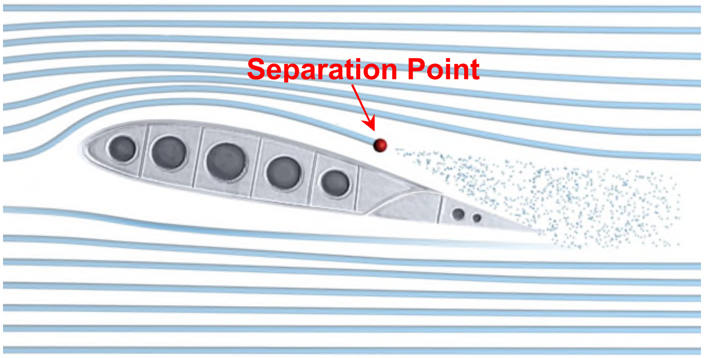
Behind the separation point airflow is turbulent with a flow reversal, lift is destroyed, and drag becomes excessively high.

TRAILING EDGE SEPARATION

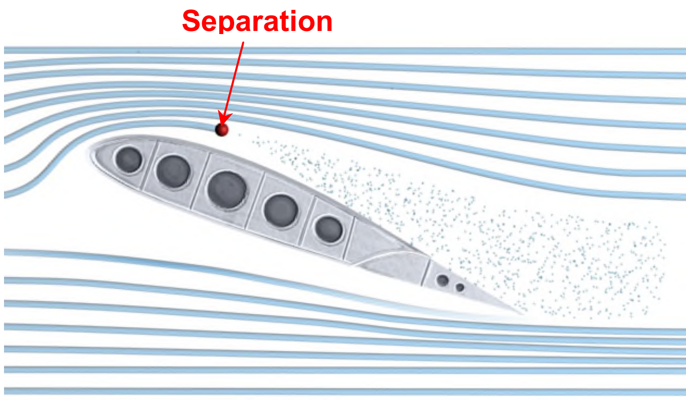
At low angles of attack on a normal subsonic wing section, the turbulent boundary layer remains attached over the rear part of the surface and little separation occurs.

As angle of attack increases, the adverse pressure gradient is increased and the boundary layer will begin to separate near the trailing edge and become turbulent.





With a further increase of the angle of attack, the point at which the boundary layer will begin to separate will move forward along the surface of the wing towards the leading edge.



As the AoA increases, a point is eventually reached where the flow over the upper surface of the wing is completely broken down and lift reduces dramatically.

The wing is now said to have STALLED.

LEADING EDGE SEPARATION

Trailing edge separation is normally found on conventional low speed wing sections. On thin high-speed wings with sharp leading edges another type of separation is found, namely leading edge separation.

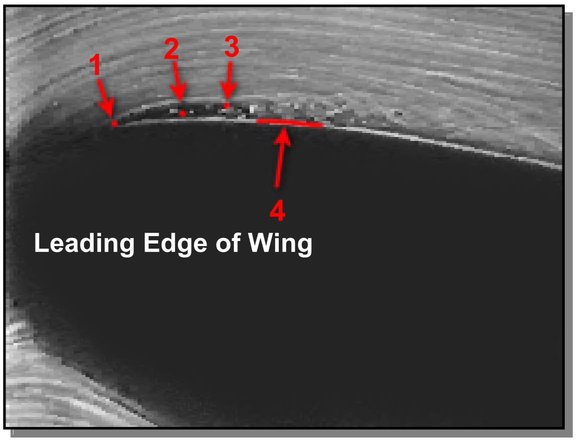
In leading edge separation, the laminar boundary layer separates from the thin leading edge of the wing before becoming turbulent; ***this is known as laminar flow separation***.

After laminar flow separation has occurred at the leading edge, transition to turbulence may take place and the now turbulent boundary layer may re-attach further down the aerofoil.

Underneath the separated boundary layer, a stationary vortex forms.

This stationary vortex is known as a **Separation Bubble**.

The image below is from an actual water tunnel test. The separation bubble can be seen clearly.



- At **1** the boundary layer separates, and the bubble is clearly visible at **2**.
- The transition to turbulence takes place at **3**, and the turbulent flow re-attaches in the vicinity of **4**.

The size of the bubble changes according to the shape of the aerofoil and may vary in size from a very small fraction of the chord (short bubble) to a length that is comparable to the length of the chord (long bubbles).

The size of the bubble determines the stall characteristics.

Short separation bubble:

A short bubble has little effect on the span wise pressure distribution of a wing (and therefore the lift-curve slope). However, when the bubble bursts, it causes a very abrupt stall.

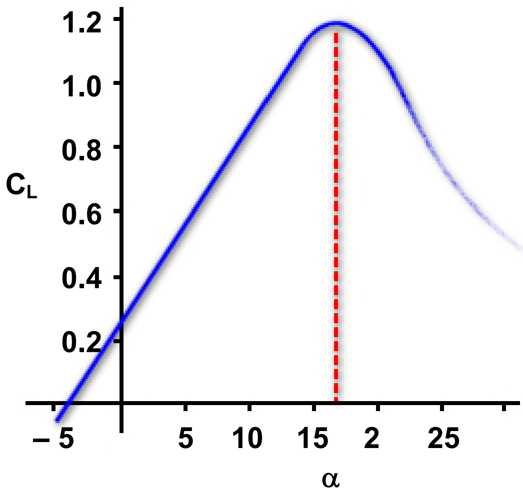
Long separation bubble:

A long bubble has a large effect on the span wise pressure distribution of a wing (reducing the lift-curve slope) even at small angles of attack. Therefore when the bubble bursts, the stall on a wing of this type is a more gradual one.

CRITICAL ANGLE

The value of C_L, and therefore lift, decreases when the airflow over the upper surface of an aerofoil is broken down at high angles of attack.

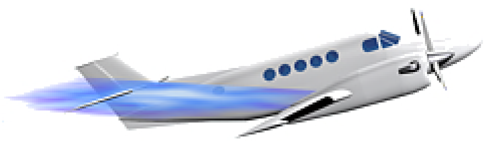
The typical lift curve shows that not all the lift is destroyed, but that the aerofoil will continue to produce a reducing amount of lift up to 90° angle of attack.



The angle of attack at which this breakdown of airflow over the wing occurs (the wing stalls) is known as the **Critical Angle**.

A subsonic aircraft will always have the same critical angle of attack for a specific wing configuration.

SYMPTOMS OF THE STALL



The high angle of attack during the stall directs the airflow directly over the tail control surfaces, which leads to the buffet.

The airflow behind the separation point is turbulent.

As the turbulent wake passes over the control surfaces, it causes a **buffet** that can clearly be felt on the control column and rudder pedals.

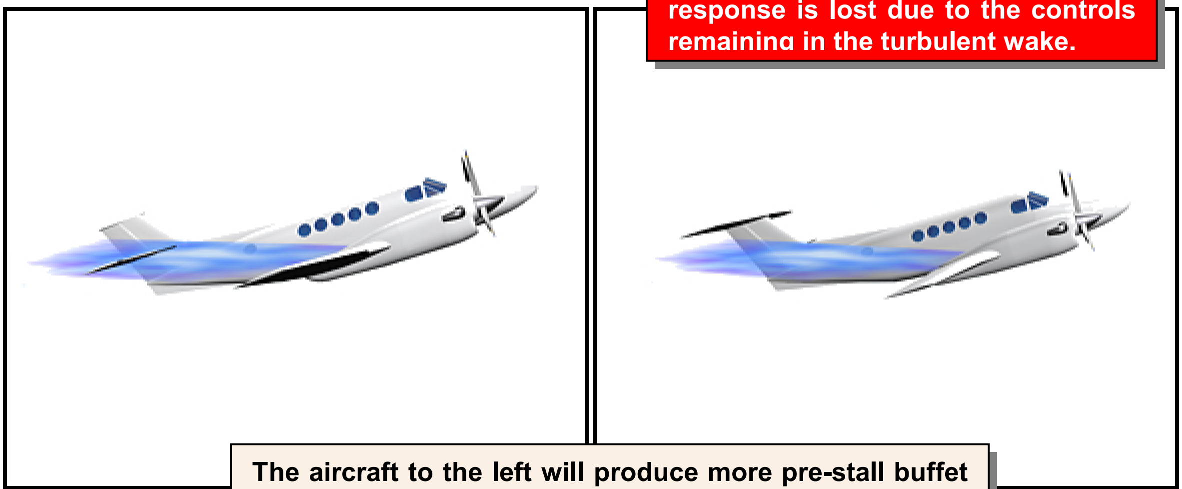
As the angle of attack is increased to close to the critical angle, the ensuing buffet will warn the pilot of the approaching stall.

On some aircraft the air will also break away at the canopy and the pilot will be able to hear the buffet.

EFFECT OF TAIL POSITION

The amount of warning received due to the buffet will differ depending on the **position of the tail control surfaces**.

The T-tail configuration can lead to what is commonly known as a "deep stall" where all rudder and elevator response is lost due to the controls remaining in the turbulent wake.



The aircraft to the left will produce more pre-stall buffet than the aircraft on the right, but recovery will be easier and safer due to better control effectiveness in the stall.

EFFECT OF FLAPS

When flaps (especially inboard flaps) are lowered, the downwash increases and therefore deflects the turbulent wake further down.

This may lead to less pre-stall buffet to warn the pilot of the impending stall and a more violent stall.

TIP STALLING

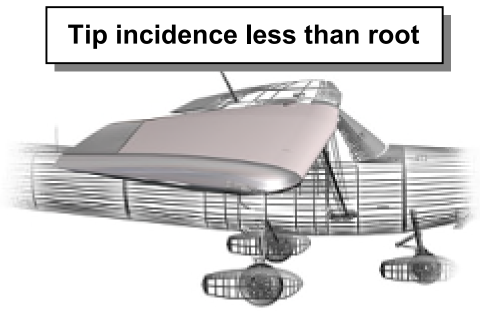
The wing of an aircraft is normally designed to stall from the wing root to the wing tip and for the following reasons:

- To induce early pre-stall buffet symptoms over the tail surface.
- To retain **aileron effectiveness** up to the critical angle of attack.
- To avoid a large rolling moment that would arise if one wing tip should stall before the other (wing drop).

There are various design features incorporated into aircraft wing design to alleviate the problem of tip stalling.

WASHOUT

If the incidence at the tip of the wing is reduced, the root of the wing will reach the critical angle of attack before the wing tip.



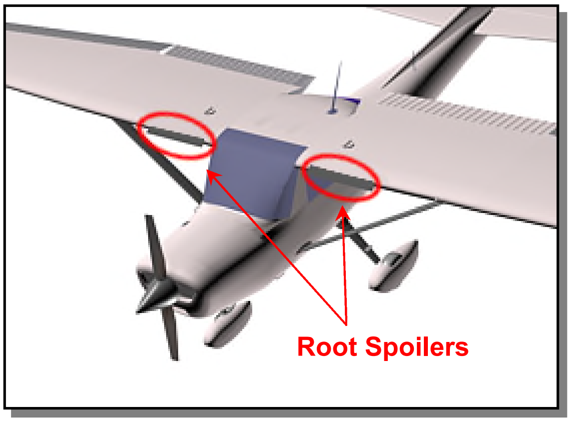
When washout is incorporated into a wing, it means that the root section angle of incidence is greater than the tip section.

This difference in incidence is normally about three degrees. With the root at a critical angle of say 16°, the tip is only at an angle of 13°.

As the tip is not stalled yet, full aileron effectiveness is retained for recovery.

Washout is a common feature on modern high-speed aircraft such as the F-15, F-16 and F-18.

ROOT SPOILERS



By making the leading edge of the wing root sharper, the airflow cannot follow the contours of the leading edge and an early stall will be induced at the root.

Root spoilers normally take on the form of V - shaped strips that are attached to the leading edges in the wing root area.

The strips cause the boundary layer to break away at a lower angle of attack than the stalling angle for that aerofoil.

Root spoilers are more often than not used on low speed aircraft.

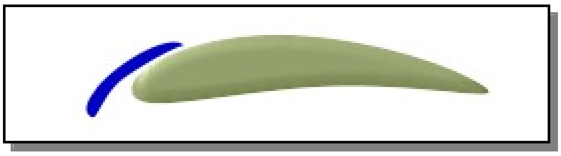
CHANGE OF SECTION

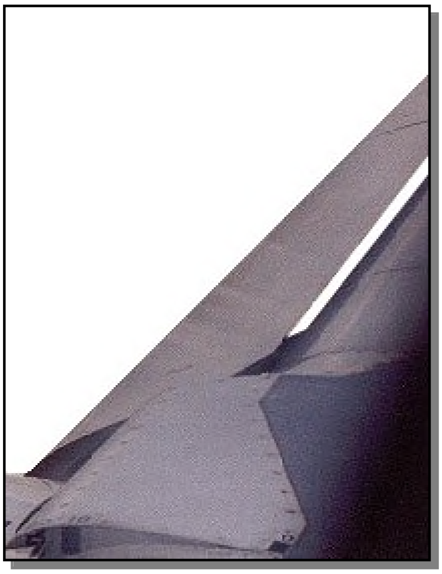
By increasing the camber towards the wing tips, the stalling characteristics will be more gradual.

In the picture of a T6-Texan, the increased camber at the wingtip is quite apparent.

SLATS AND SLOTS

Slats and/or slots on the leading edge of the outer portion of a wing will increase the stalling angle of that wing.





STALLING SPEED

For an aircraft maintaining level flight the two variable factors in the lift formula are C_L and speed.

If power is reduced the drag will reduce the speed and from the formula; **the lift**.

To maintain level flight, lift must be kept constant and the only factor that can be varied to keep lift constant is $\mathbf{C_L}$ or angle of attack.

If speed is reduced, the angle of attack (and therefore C_L) must be increased to restore lift to its original value.

Any further reduction in speed will necessitate a further increase in angle of attack - thus each succeeding lower IAS will correspond to each succeeding higher angle of attack.

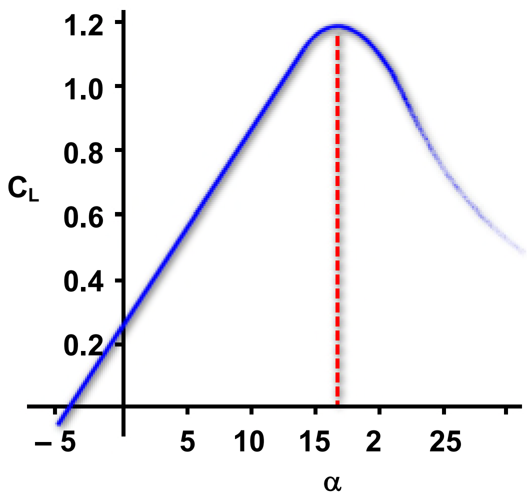
To obtain the speed for the corresponding angle of attack, it is necessary to have a look at the lift formula.

$$L = C_L \tfrac{1}{2} \rho_0 V^2 S$$

Note: V^2 is TAS

The speed for a corresponding angle of attack can be derived as follows:

$$V^2 = \frac{L}{C_L \tfrac{1}{2} \rho_0 S} \quad \text{or} \quad V = \sqrt{\frac{L}{C_L \tfrac{1}{2} \rho_0 S}}$$



At a certain IAS, the wing will reach its stalling angle of attack. Beyond this angle any attempt to increase the angle of attack any further, will lead to a stall.

Therefore: the stalling speed of an aircraft is the speed at which, for a given set of conditions, the aircraft is at its **stalling angle of attack (also known as the critical angle)**.

Although the stalling speed may vary, the stalling angle of attack will always remain the same for any particular aerofoil shape.

To derive the speed corresponding to the critical angle of attack, the value of the C_L in the lift formula must be the $C_L$max:

$$V = \sqrt{\frac{L}{C_{Lmax} \tfrac{1}{2} \rho_0 S}}$$

BASIC STALLING SPEED

The most useful stalling speed is the speed at the critical angle of a clean aircraft at straight and level flight and this speed is known as the Basic Stalling Speed.

Definition:

Basic Stalling Speed can be defined as that speed where a clean aircraft of *stated weight* and with engines throttled back, can no longer maintain straight and level flight.

In straight and level flight, Lift is equal to Weight, therefore:

$$V_B = \sqrt{\frac{W}{C_{Lmax} \frac{1}{2} \rho_0 S}}$$

where V_B is basic stalling speed.

FACTORS AFFECTING BASIC STALLING SPEED

The factors affecting the basic stalling speed are:

- Change in Weight
- Manoeuvre (Load Factor)
- Configuration (Changes in C_{Lmax})
- Power
- Slipstream

CHANGE IN WEIGHT

The definition for basic stalling speed states that the basic stalling speed is valid for a stated weight.

If the weight of an aircraft should change (fuel burn-off or dropping or firing of ordance), the weight will change, and therefore also the stalling speed.

There is a relationship between the basic stalling speeds at two different weights and it can be obtained from:

$$V_{B_2} : V_{B_1} = \sqrt{\frac{W_2}{C_{Lmax}\frac{1}{2}\rho_0 S}} : \sqrt{\frac{W_1}{C_{Lmax}\frac{1}{2}\rho_0 S}}$$

the denominators on the right are the same, therefore

$$V_{B_2} : V_{B_1} = \sqrt{W_2} : \sqrt{W_1} \qquad \text{or} \qquad \frac{V_{B_2}}{V_{B_1}} = \sqrt{\frac{W_2}{W_1}}$$

from which $$V_{B_2} = V_{B_1}\sqrt{\frac{W_2}{W_1}}$$

Note: V_{B_2} and V_{B_1} are the basic stalling speeds at W_2 and W_1.

MANOEUVRE (LOAD FACTOR)

The same method that is used to derive the new basic stalling speed with a change in weight can be used to work out the manoeuvre stalling speed (V_M) during any manoeuvres, as long as the load factor is known.

$$V_M : V_B = \sqrt{\frac{L}{C_{Lmax}\frac{1}{2}\rho_0 S}} : \sqrt{\frac{W}{C_{Lmax}\frac{1}{2}\rho_0 S}}$$

the denominators on the right are the same,

$$V_M : V_B = \sqrt{L} : \sqrt{W} \qquad \text{or} \qquad \frac{V_M}{V_B} = \sqrt{\frac{L}{W}}$$

from which $$V_M = V_B\sqrt{\frac{L}{W}}$$

The relationship of $\frac{L}{W}$ is also known as load factor

$$V_M = V_B\sqrt{n}$$

The load factor (n) is normally indicated on an **accelerometer** (if fitted); otherwise it can be calculated in a level turn by using the amount of bank indicated on the artificial horizon.

CONFIGURATION

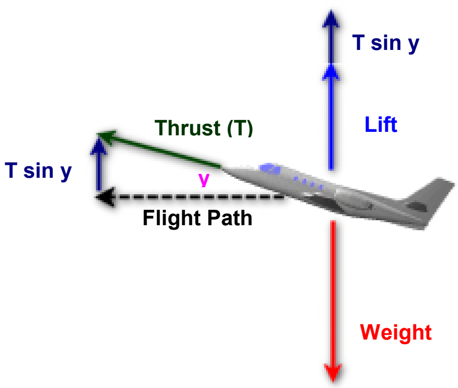
Any change in C_{Lmax} due to the lowering of flaps or the use of leading edge slats, will cause the stalling speed to change (an increase in C_{Lmax} will lead to a decrease in the stalling speed and vice versa).

$$V_B = \sqrt{\frac{W}{C_{Lmax}\frac{1}{2}\rho_0 S}}$$

From the formula above, it can be seen that stalling speed is inversely proportional to C_{Lmax} in level flight.

Therefore $V_B \propto \dfrac{1}{\sqrt{C_{Lmax}}}$

POWER



An aircraft that is in a stall situation will have a high nose attitude with no power.

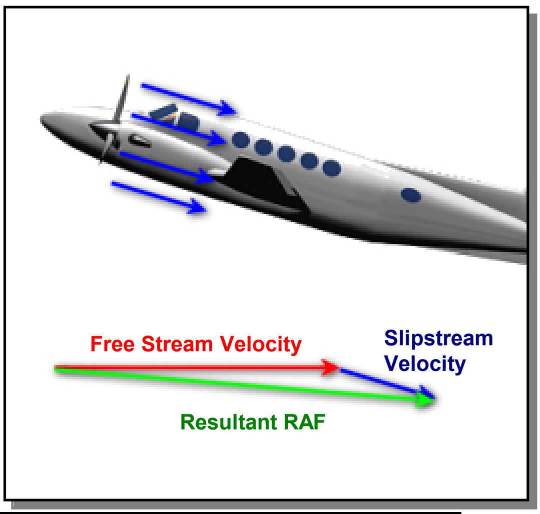
If, however, some power is left on, a vertical thrust component will be present (T sin y).

This component will reduce the amount of lift required from the wings (AOA), and therefore the critical AOA will be obtained at a lower speed.

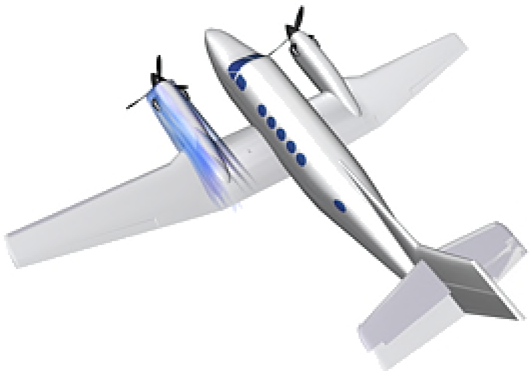
SLIPSTREAM

When considering a propeller-powered aircraft, the velocity of the slipstream behind the propellers causes an additional effect.

When the slipstream vector is added to the free stream vector, it will result in a change in the RAF over that part of the wing affected by the propellers.



The resultant RAF will lead to a reduction in the effective angle of attack, which in turn will result in a higher attitude at the stall (Remember, the aircraft will still stall at the same critical angle of attack).



An additional effect of slipstream is more lift being produced by the wing area directly behind the propellers. The extra lift helps to support the weight of the aircraft at a lower IAS thereby **reducing the stalling speed**.

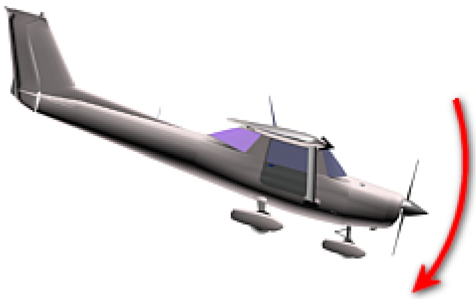
From the graphic it can also be seen that only the inboard sections of the wings are affected.

The lower angle of attack of the inboard sections will lead to a progressive stall from the tip to the root and reduce the possibility of a wing drop and its severity.

RECOVERY FROM THE STALL

Most aircraft are designed to pitch nose-down when the aircraft stalls.

This action reduces the angle of attack, and airflow over the wings is restored.

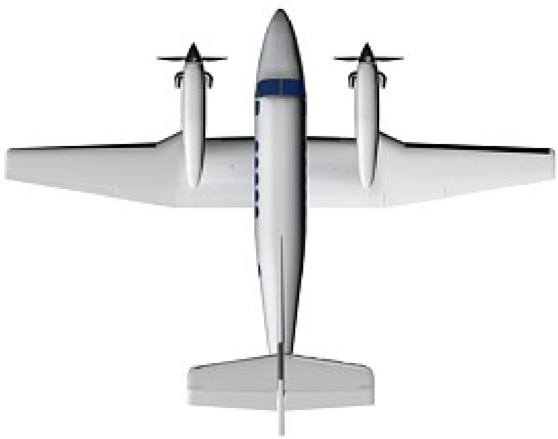


The general recovery from the stall is to decrease the angle of attack; therefore the automatic nose down tendency assists in stall recovery.

If the stall is not recovered early enough, the result may be that the aircraft enters a spin, which is more difficult to recover from.

WING PLAN FORMS AND STALLING

INTRODUCTION



The plan form of a wing is the geometrical shape of a wing viewed from above. The importance of planform lies in the fact that it largely determines the amount of lift and drag obtainable from a stated wing area and thus, has a pronounced influence on the stalling angle of the wing.

ASPECT RATIO

The formula for determining aspect ratio is:

$$\text{Aspect Ratio} = \frac{\text{Span}^2}{\text{Area}}$$

By simplifying this formula a second formula with which aspect ratio can be calculated is deducted:

$$\text{Aspect Ratio} = \frac{\cancel{\text{Span}} \times \text{Span}}{\cancel{\text{Span}} \times \text{Cord}}$$

$$\text{Aspect Ratio} = \frac{\text{Span}}{\text{Cord}}$$

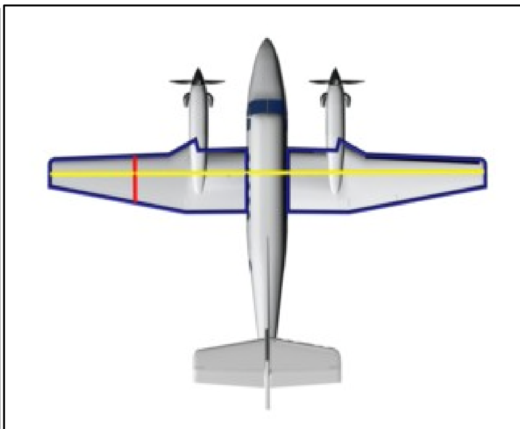
The aspect ratio (A) can be determined according to method a or b:

Method A

$$\text{Aspect Ratio} = \frac{\text{Span}^2}{\text{Area}}$$

$$= \frac{54.5^2}{303}$$

$$= 9.8$$



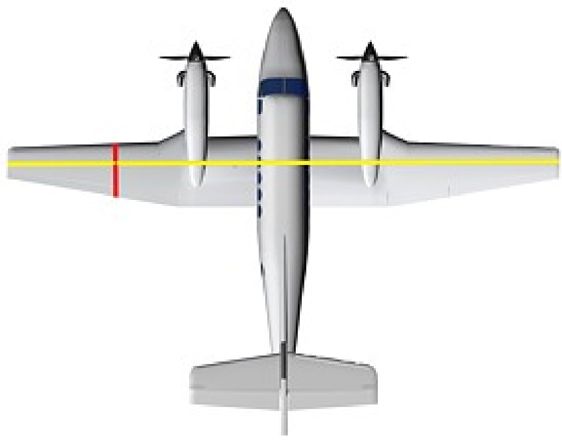
Method B

$$\text{Aspect Ratio} = \frac{\text{Span}}{\text{Cord}}$$

$$= \frac{54.5}{5.6}$$

$$= 9.8$$

By comparing the two aircraft shown below it is evident that as the chord length or the wing area decrease in relation to the span, aspect ratio increases. The opposite is also true.



Aspect Ratio = $\frac{\text{Span}}{\text{Cord}}$

A = $\frac{37}{10.88}$

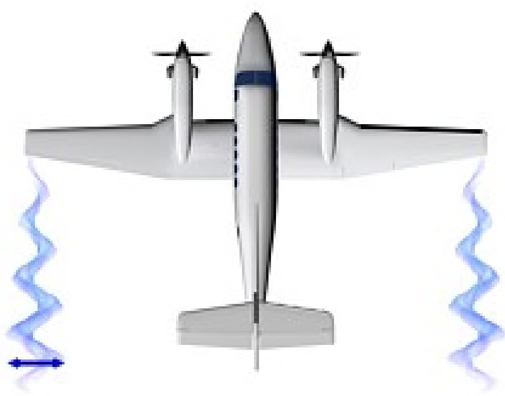
= 3.4 : 1

Aspect Ratio = $\frac{\text{Span}}{\text{Cord}}$

A = $\frac{54.5}{5.6}$

= 9.8 : 1

Referring back to the lesson on lift and the formation of trailing edge and wingtip vortices, it was shown that the induced downwash was the cause of induced drag. The downwash imparted to the air is a measure of the lift provided by the wing.



Induced drag formula:

The amount of induced drag under a given set of conditions can be found from the formula:

Induced drag = $\frac{kC_L^2}{\pi A}$

Where $\frac{kC_L^2}{\pi A}$ = the coefficient of the induced drag

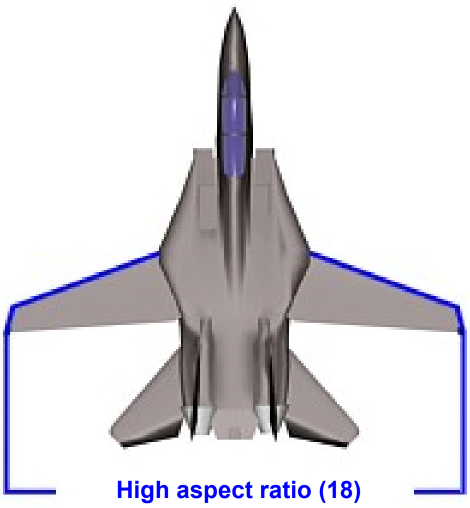
And A = aspect ratio

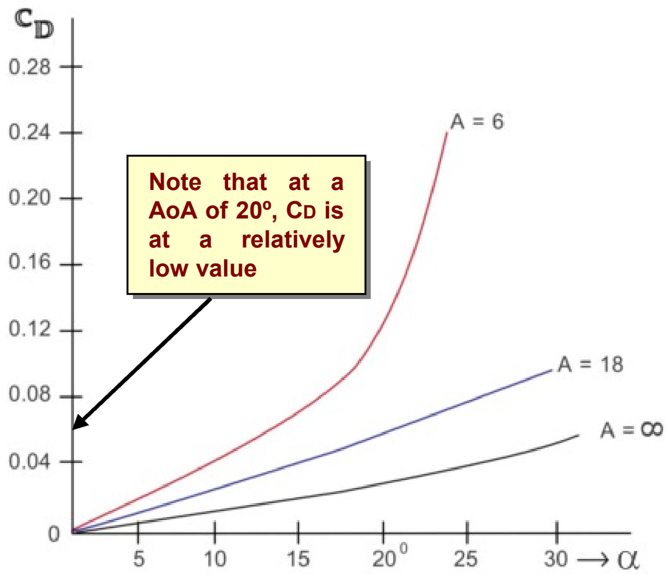
Induced drag is inversely proportional to Aspect Ratio. Refer to the **Induced Drag Formula** - the higher the Aspect Ratio of a wing design, the lower the amount of induced drag ***(i.e. Wingtip Vortices)*** created when the wing is developing lift.

As the Aspect Ratio of a wing increases for a given Angle of Attack (AOA), the coefficient of drag (**C_D**) will decrease accordingly.

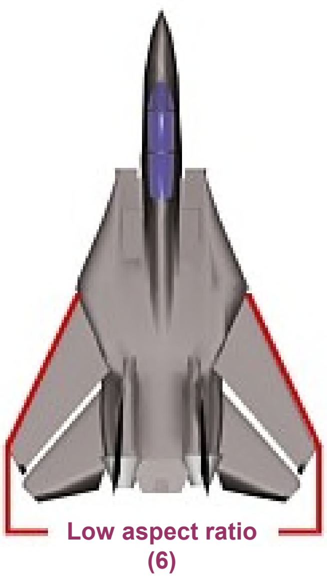
By using variable sweep, the wingspan can be altered, thus resulting in a change in Aspect Ratio and C_D.

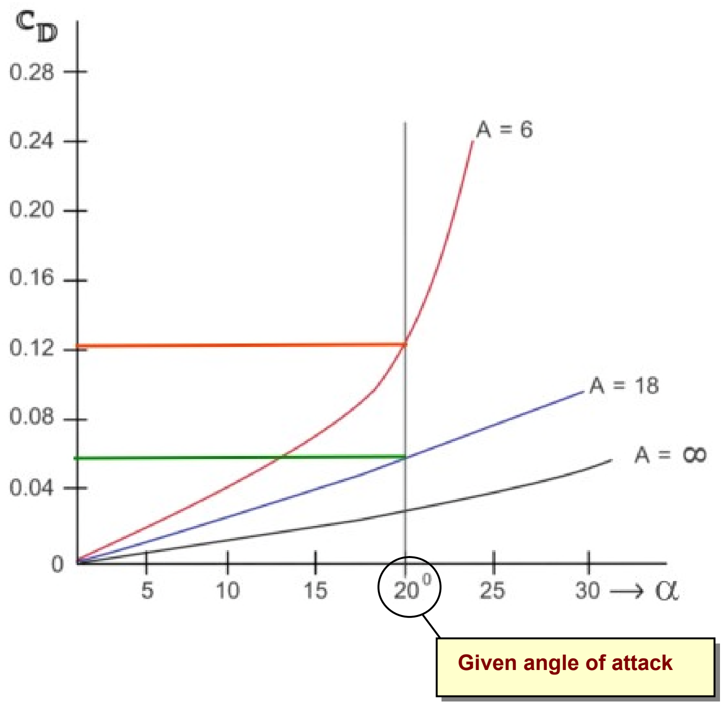
The graph plots AOA against C_D. Consider the wing of a variable sweep aircraft. With the wings swept forward, the aspect ratio has a high value of 18 : 1.



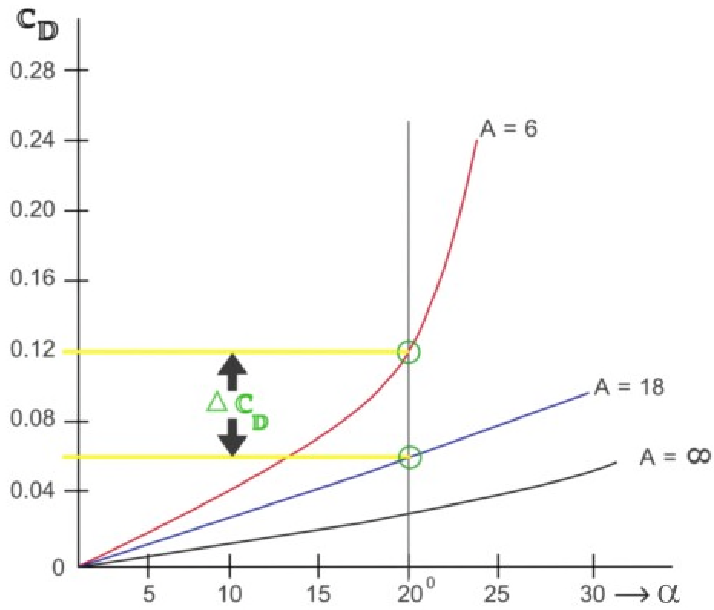


With the wings swept back, the aspect ratio has a low value of 6 : 1. From the graph it is clear that at the same AOA, the lower aspect ratio (**A = 6**) has a much higher C_D value than the higher aspect ratio (**A = 18**).





The difference in coefficient of drag (**ΔC_D**) indicated on the graph between a wing with a high, and a wing with a low Aspect Ratio is important. As the AOA line moves to a higher value, the C_D increases as the plotted line curves to a higher C_D value. This has a marked influence on the angle at which a wing stalls.



From the previous explanation it is possible to see the relationship between Aspect Ratio and Induced Drag clearly. Induced drag is increased when aspect ratio is decreased.

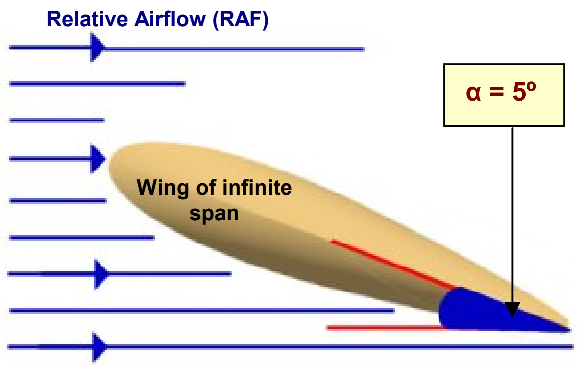
Induced Drag is inversely proportional to Aspect ratio.

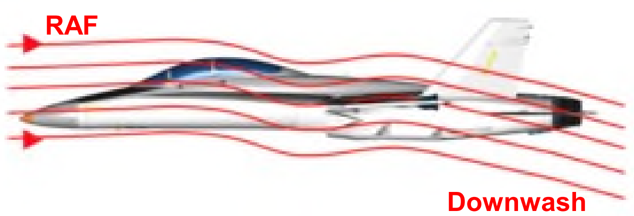
Stalling is the term given to the concept when the AOA of an aerofoil is so high that the airflow over the top of the aerofoil is broken down and very little lift is developed. The angle at which the airflow over a wing breaks down with an accompanying marked reduction in the Coefficient of Lift is called the critical angle.

The stall can be defined as the marked reduction in the lift coefficient that accompanies the breakdown of the airflow over the wing.

In other words the breakdown of the airflow over the wing will occur when the wing reaches its Critical Angle.

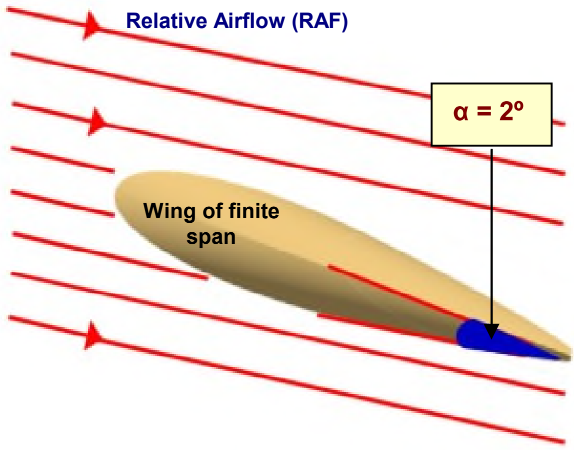
During level flight, a wing of infinite length has no induced downwash ***(and thus no induced drag)***. An infinite wing will therefore stall when the angle of attack measured relative to the "horizontal" total airstream past the wing, reaches the critical angle.





However, no aircraft has a wing of infinite length and wings of finite length have wingtip vortices and induced **downwash**. The induced downwash produces a downward component in the direction of the total airflow behind the wing.

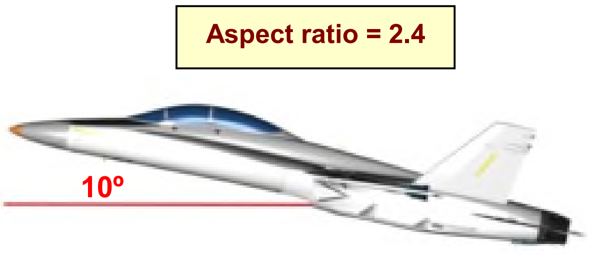
This downward component of the airflow behind the wing leads to a reduction in the effective angle of attack of that wing.

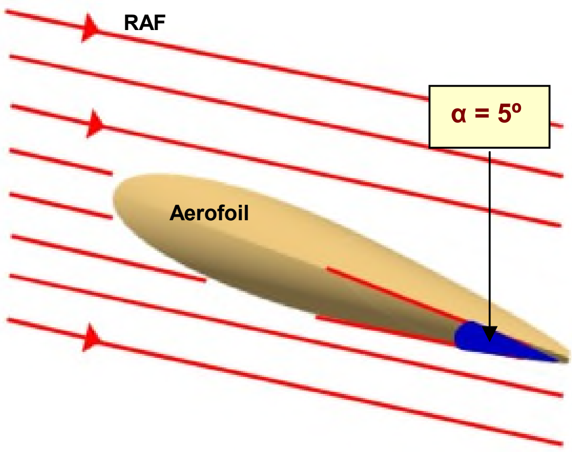


As was mentioned earlier, Aspect ratio has a marked influence on Induced Drag (Vortex Drag). It follows then that Aspect Ratio will also have a significant influence on Critical -and stalling angles. Let's consider two aircraft at the same angle relative to the "horizontal" component of the Relative Airflow (RAF), **i.e. 10º:**

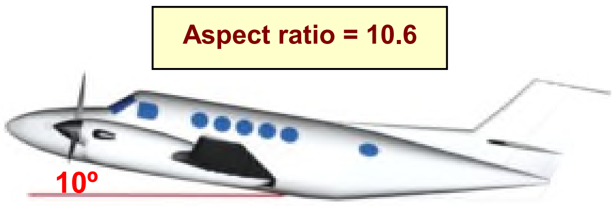
If the airflow around aircraft **A** is analysed, it can be seen that there is a substantial downward component imparted to the flow over the aircraft due to the high Induced Drag, resulting in an effective AoA of only 5º. Aircraft **B**, with much less Induced Drag due to the higher Aspect Ratio on the other hand, has an effective AOA of 8º.

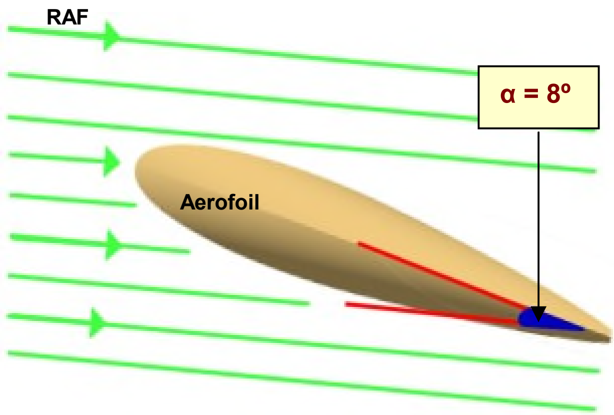
A



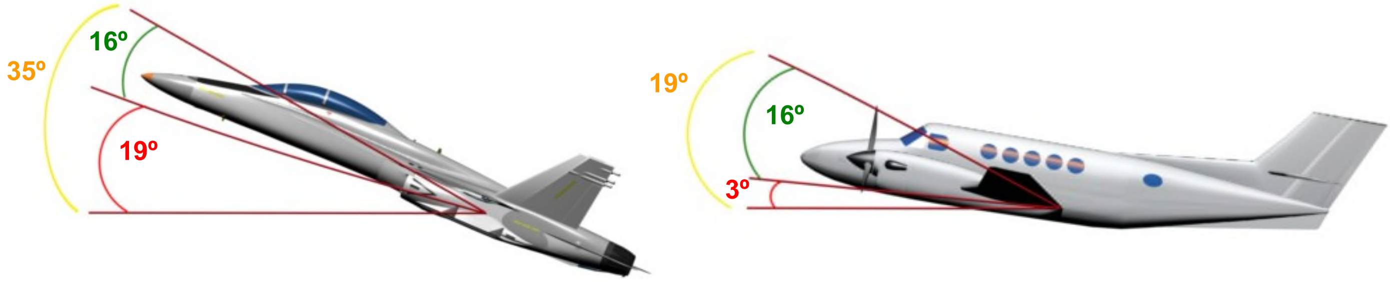


B





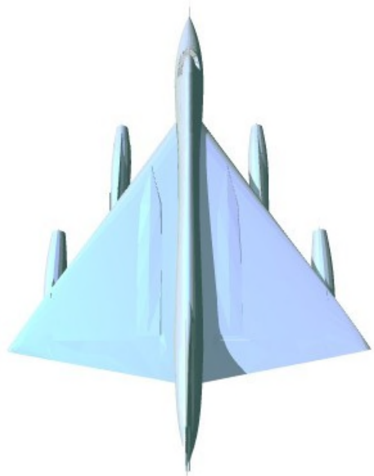
The stall only occurs when the effective AOA reaches the Critical angle. The aircraft with the Low Aspect Ratio ***(High Induced Drag)*** will have a higher Stalling Angle than the aircraft with the High Aspect Ratio when measured relative to the "horizontal" total air stream. The differences in the Stalling Angles vary by approximately the angular difference in the Induced Downwash between the two aircraft.



Critical Angle + RAF Angle Due To Downwash = Stalling Angle

The reduced effective AoA of very low aspect ratio wings can delay the stall considerably. Some delta wings have no measurable stalling angle up to 40 degrees or more inclination to the flight path. At such a high angle the drag is so high that the flight path is usually inclined downwards at a steep angle to the "horizontal".

This situation can be deceptive as the aircraft can have a rapid rate of descent with a possible loss of stability and control while the angle of the aircraft relative to the horizon can be very shallow. This is called the "Deep Stall" or "Super Stall".



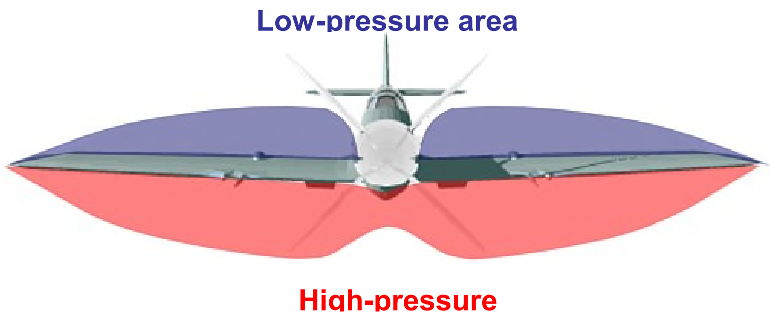
AWACS, Transport, Patrol and Maritime Aircraft that are continually operated at high lift coefficients, need high aspect ratio wings in order to minimize induced drag; thus cutting back on fuel consumption and prolonging endurance.

Although high aspect ratio wings will minimize induced drag, long thin wings increase weight and have relatively poor stiffness characteristics. Another negative feature is the fact that vertical gusts have a far more pronounced effect on wings when aspect ratio is increased.

In general it can be said that the lower the cruising speed of an aircraft, the higher the aspect ratios that can be utilised effectively. Normally aircraft configurations that are developed for high-speed flight ***(especially supersonic flight)*** operate at relatively low lift coefficients and demand great aerodynamic cleanness. This normally results in the development of low aspect ratio planforms.

TAPER AND STALL PATTERNS

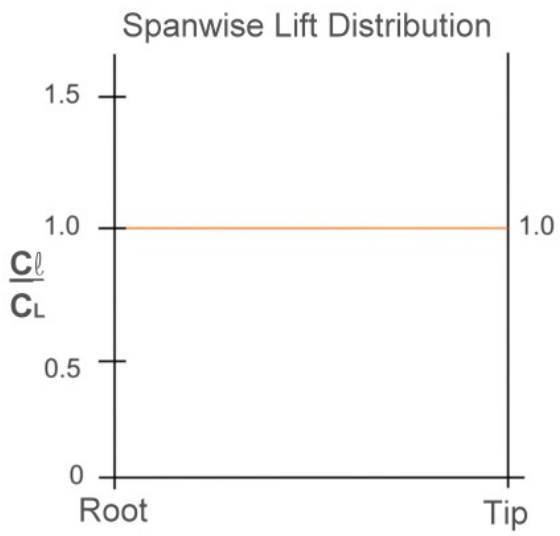
The aspect ratio of a wing is the primary factor in determining the three-dimensional characteristics of a wing and its drag due to lift ***(e.g. vortices)***. The distribution of the wing area throughout the span has a pronounced effect on the flow patterns around the wing, but in broad terms it can be said that a typical lift distribution pattern is arranged in an elliptical fashion around an aerofoil. Here follows a description of different planforms and how their stall patterns look when viewed from above.



The annotations on the graphic are used purely for reasons of simplicity. The area referred to as a high-pressure area on the graphic, is actually a low-pressure area of lesser intensity than that of the low-pressure area above the wing.

ELLIPTICAL WING

With an elliptical wing planform, each section of the wing works at exactly the same local lift coefficient and the induced down flow of the wing is uniform throughout the span.



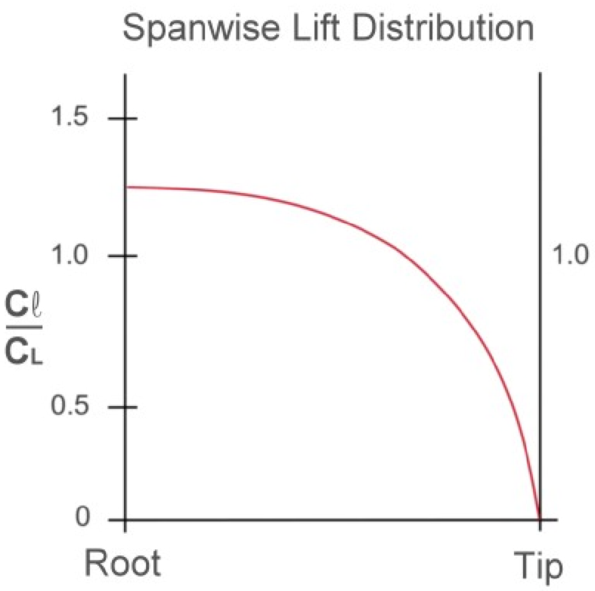
The elliptical wing is; in the aerodynamic sense; the most efficient planform, as it has a uniform lift coefficient and the downwash incurs the least induced drag for a given aspect ratio. The merit of any wing planform is therefore measured by the closeness with which the C_L distribution and the downwash approach that of the elliptical wing.

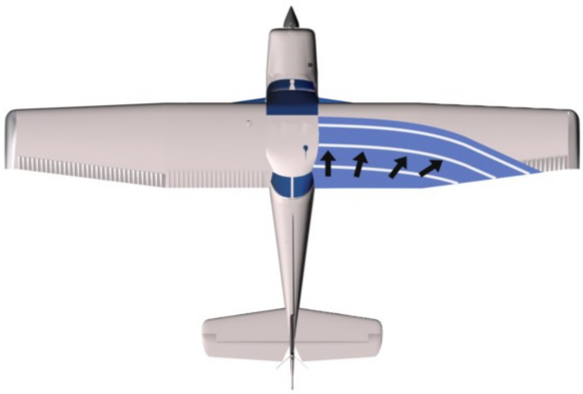
The constant lift coefficient throughout the span from the wing root to the tip causes the wing as a whole, to reach a stall at essentially the same angle of attack. The stall will begin and progress uniformly along the whole length of the span.

RECTANGULAR WING

A characteristic of the rectangular wing is a strong vortex at the tip. The local downwash is high at the tip and low at the root. This change in downwash causes local induced AOA to decrease progressively from the root to the tip, with the average AOA for the wing found midway along the span.

The wing area near the wing tip is large compared to the lift in that area, and the wing loading is therefore, low. Because of the high wing loading at the root, the stall will thus start at the trailing edge of the wing root and then spread outward and forward as the stall progresses.

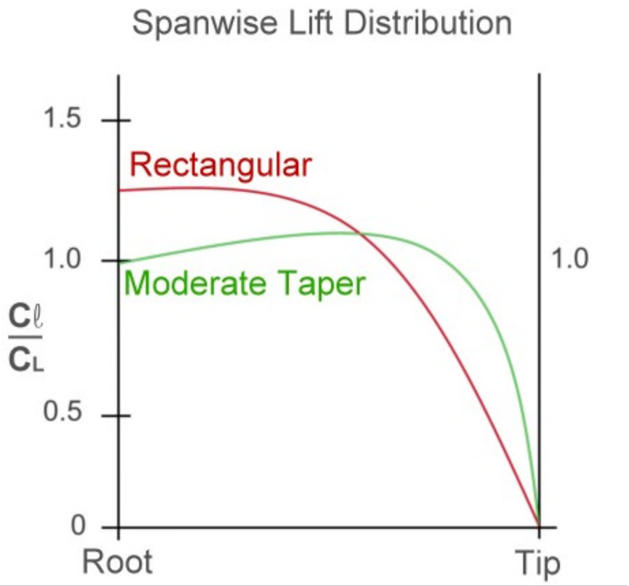




The **C_l / C_L** approaches zero near the wing tip producing the maximum loading at the wing root.

MODERATE TAPER

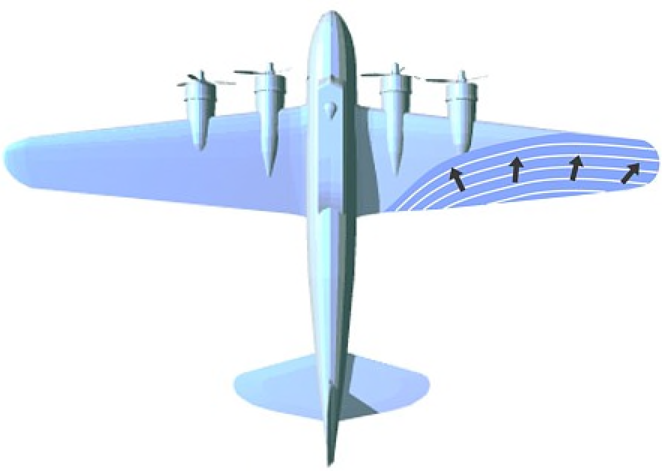
A wing with moderate taper has a lift distribution pattern that is very similar to a the pattern as found around a rectangular wing, the only difference being that the wing loading at the root is slightly less for the moderate taper wing. This implies that the stall will still start closer to the root ***(not as close as on the rectangular wing though)*** at the trailing edge and then progress towards the wing tip.

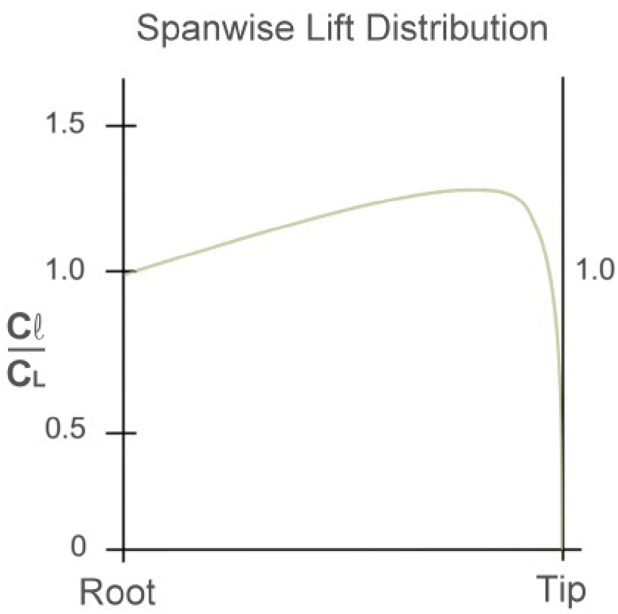


Note the similar values found midway along the span of the two different tapers.

HIGH TAPER

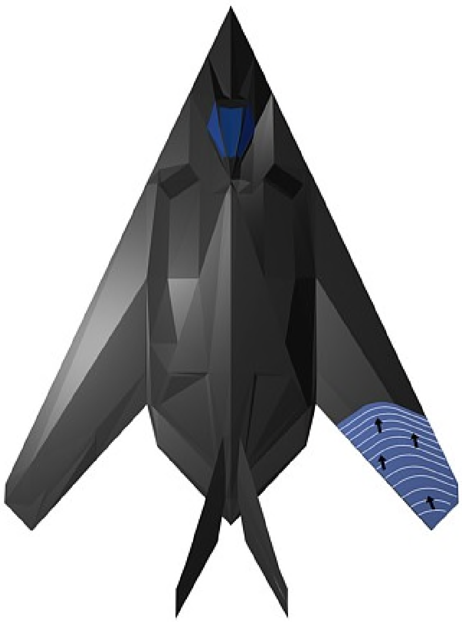
A wing with a high taper ratio will have a higher wing loading towards the wing tip than an elliptical - or rectangular wing. This means that the wing tip area is developing more lift per square meter than the root of the wing and thus the stall will also tend to occur more towards the wingtip.

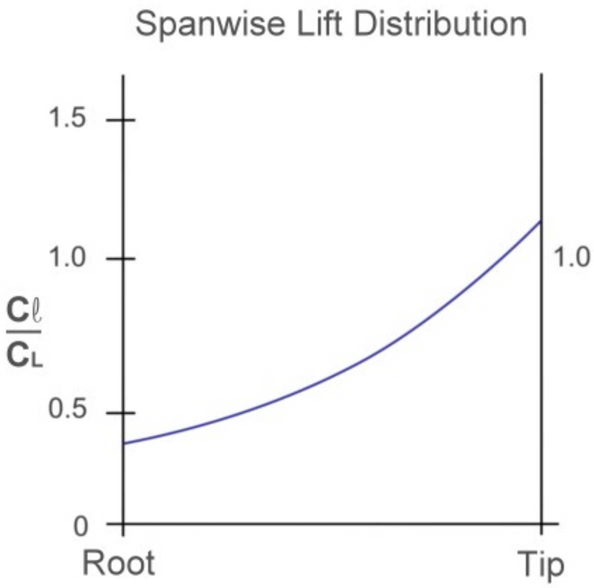




SWEPT WING

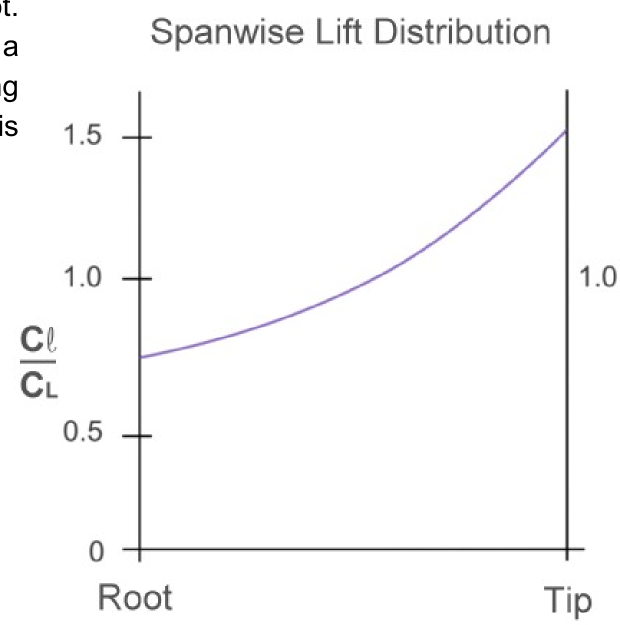
With a swept wing the boundary layer tends to change direction and flow towards the wing tips. The span wise drift sets up a tendency towards tip stalling, since it thickens the boundary layer over the outer parts of the wing and makes it more susceptible to separation, bringing with it a sudden reduction in the coefficient of lift over the wing tips. Thus the stall occurs at the wing tips.

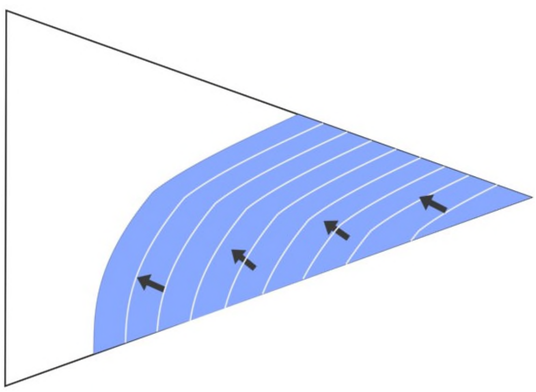




POINTED TIP

The pointed tip has the greatest downwash at the root with an upwash tendency towards the tip. Due to the increased effective angle of attack caused by the upwash, a greater coefficient of lift is encountered at the tip of the wing. The stall occurs at the wing tip and progresses along the span towards the root. Unless extensive tailoring is applied to the wing, a stall can occur in any condition of lift. This wing has no practical application for an aircraft that is designed to be subsonic in performance.



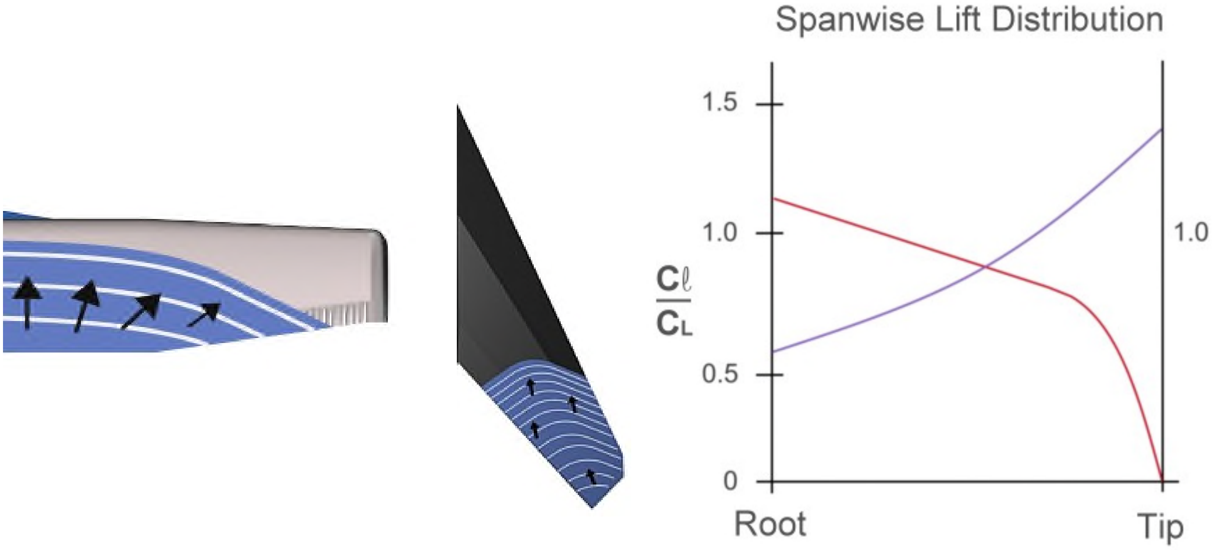


STALL PATTERNS AND PLAN FORMS

Straight (Rectangular) wing aircraft, with the stall starting at the roots, seem to have advantages over swept-winged aircraft as far as the stall characteristics are concerned.

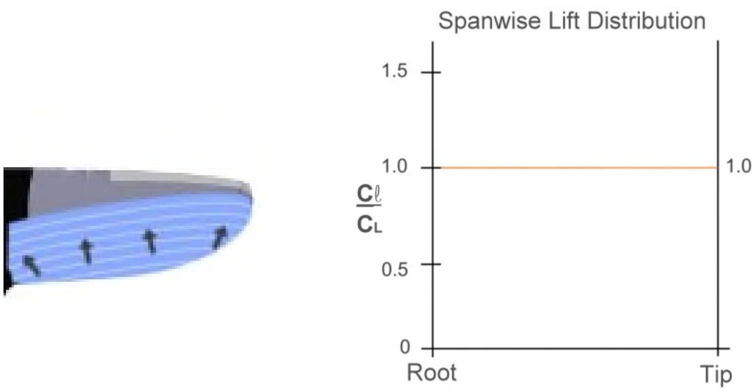
- Firstly, there is a more adequate stall warning, caused by separated air buffeting the fuselage and tail surfaces.

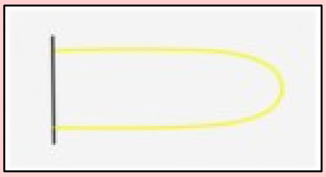
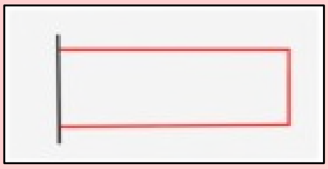
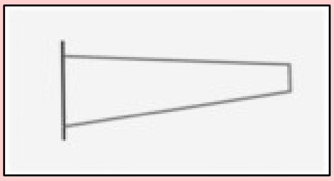
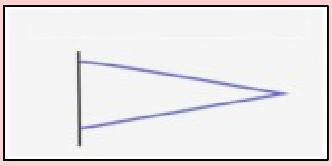
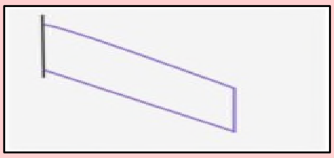
- Secondly, the ailerons of the straight winged aircraft are not enveloped in the stalled air until the stall has progressed outwards from the wing root, compared to the relatively early envelopment from stalling of the swept wing. Swept-winged aircraft are usually equipped with stall devices to compensate for the lack of buffet warning.



Aerodynamically, the elliptical wing is the ideal since it provides a minimum of induced drag for a given aspect ratio. Furthermore, the lift, as well as the wing loading is distributed evenly along the wingspan, causing the stall to occur simultaneously over the whole wing.

The only negative aspect that has to be kept in mind is that there will be little advance warning of a complete stall as the whole wing stalls simultaneously.



Shape	Type	Stall Origin	Advantages	Disadvantages
	Elliptical	Whole Trailing Edge	Even Lift Distribution Throughout the span	Little advance warning of a complete stall
	Rectangular	Root	Adequate stall warning buffet	Aerodynamically inefficient
	Moderate Taper	1/3 from the root	Even lift distribution, more controllable near stall than elliptical wing	Only low speed application
	High Taper	Halfway	Less induced drag than rectangular wing	Strong "tip Stall" tendency
	Pointed Tip	Tip	Limited supersonic application	Tip permanently stalled unless extensively tailored
	Sweepback	Tip	Improved handling characteristics during high speeds	Strong "tip Stall" tendency