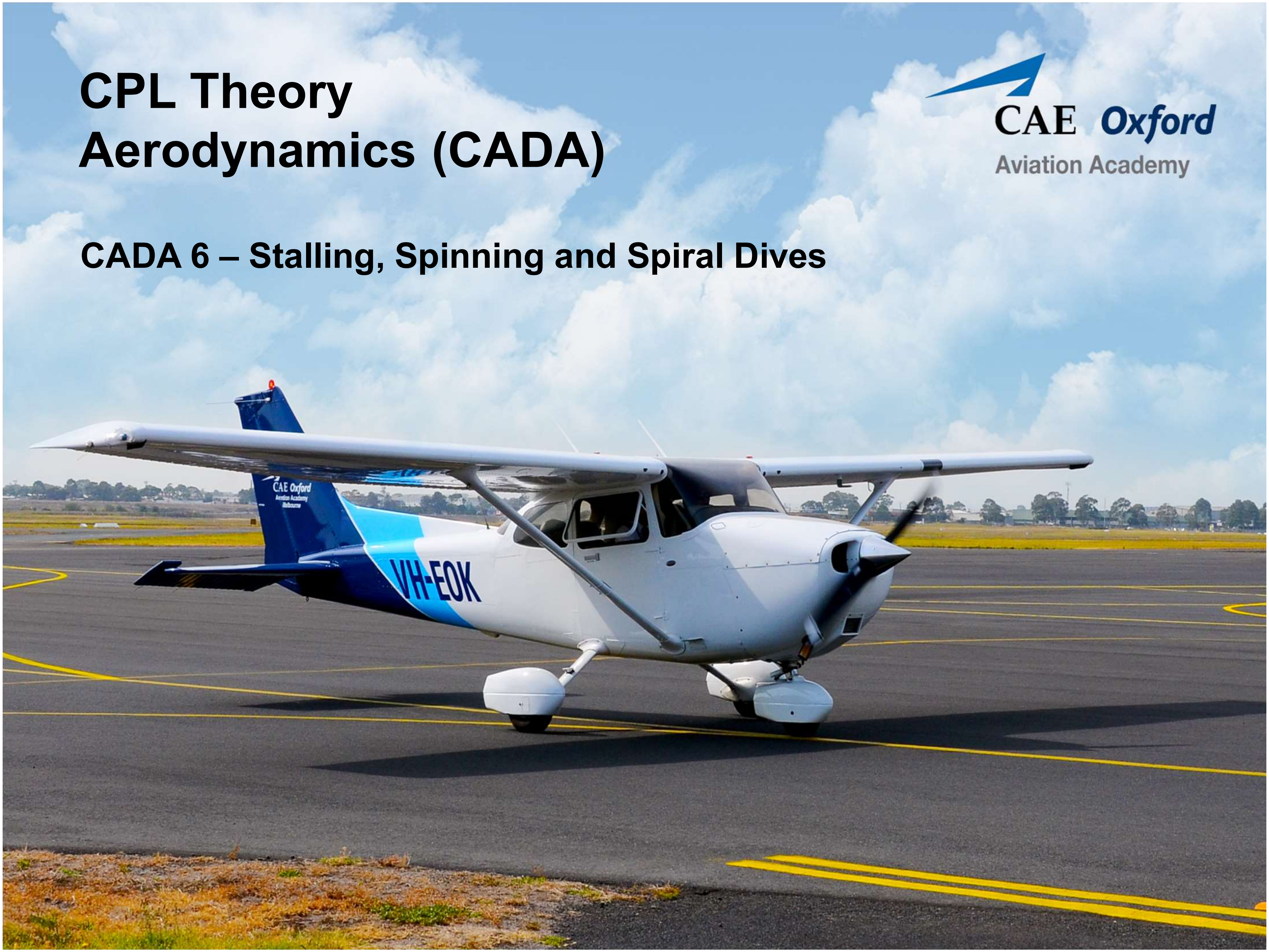
CPL Theory
Aerodynamics (CADA)

CAE Oxford
Aviation Academy

CADA 6 – Stalling, Spinning and Spiral Dives



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2. Related Documents

Related Documents	Document Identification

CADA 6 – Stalling, Spinning and Spiral Dives

Amendments made to this document since the previous version are listed below. All amendments to this document have been made in accordance with CAE OAAM's document management procedure.

Slide	Changes

STALLING DEFINITION

Stalling

- Most of you have probably heard of an aircraft "stalling" before and most of you probably know that it is generally undesirable!
- So what is an aircraft stall?

"Stalling is the significant breakdown of streamline flow into turbulence over an aerofoil."

WHEN IS AN AIRCRAFT STALLED?

Stalling

- An aircraft can be said to be “stalled” in the following situation:

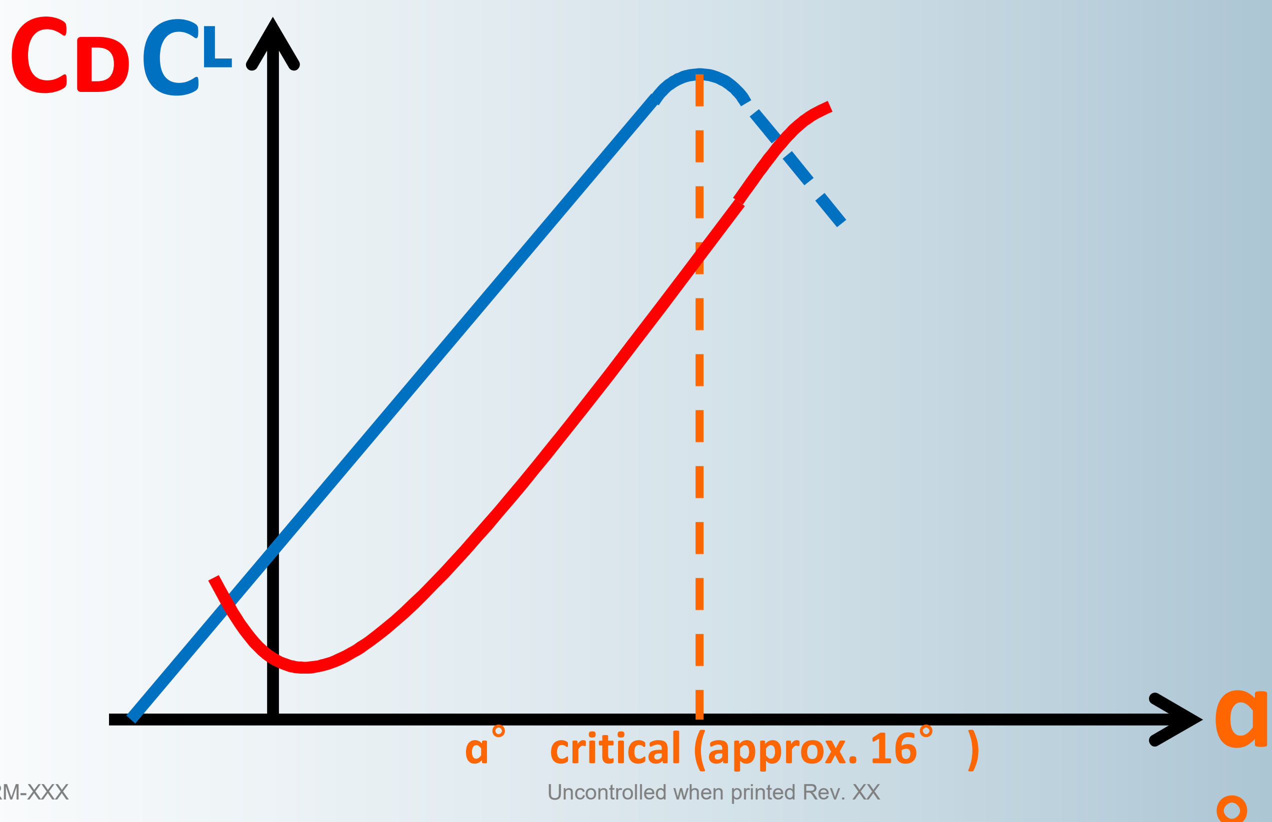
The Critical Angle of Attack of the wings is exceeded

WHY IS STALLING BAD?

Why is stalling bad?

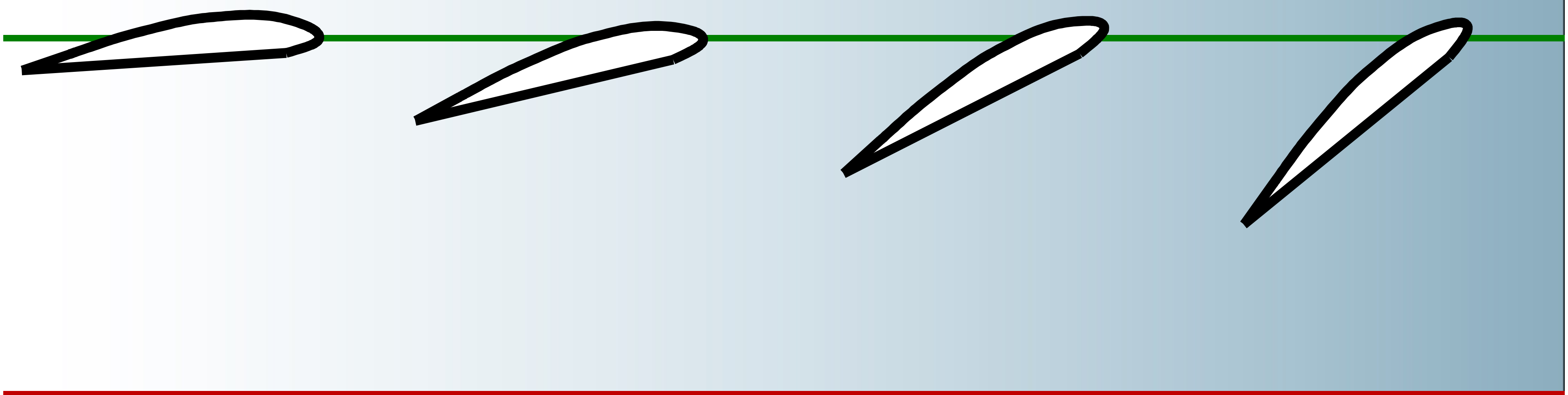
- When an aircraft stalls, it will experience a reduction in lift (about 10-20%). This means lift will no longer balance weight and the aircraft will descend

- We also get a large increase in drag, seen below:



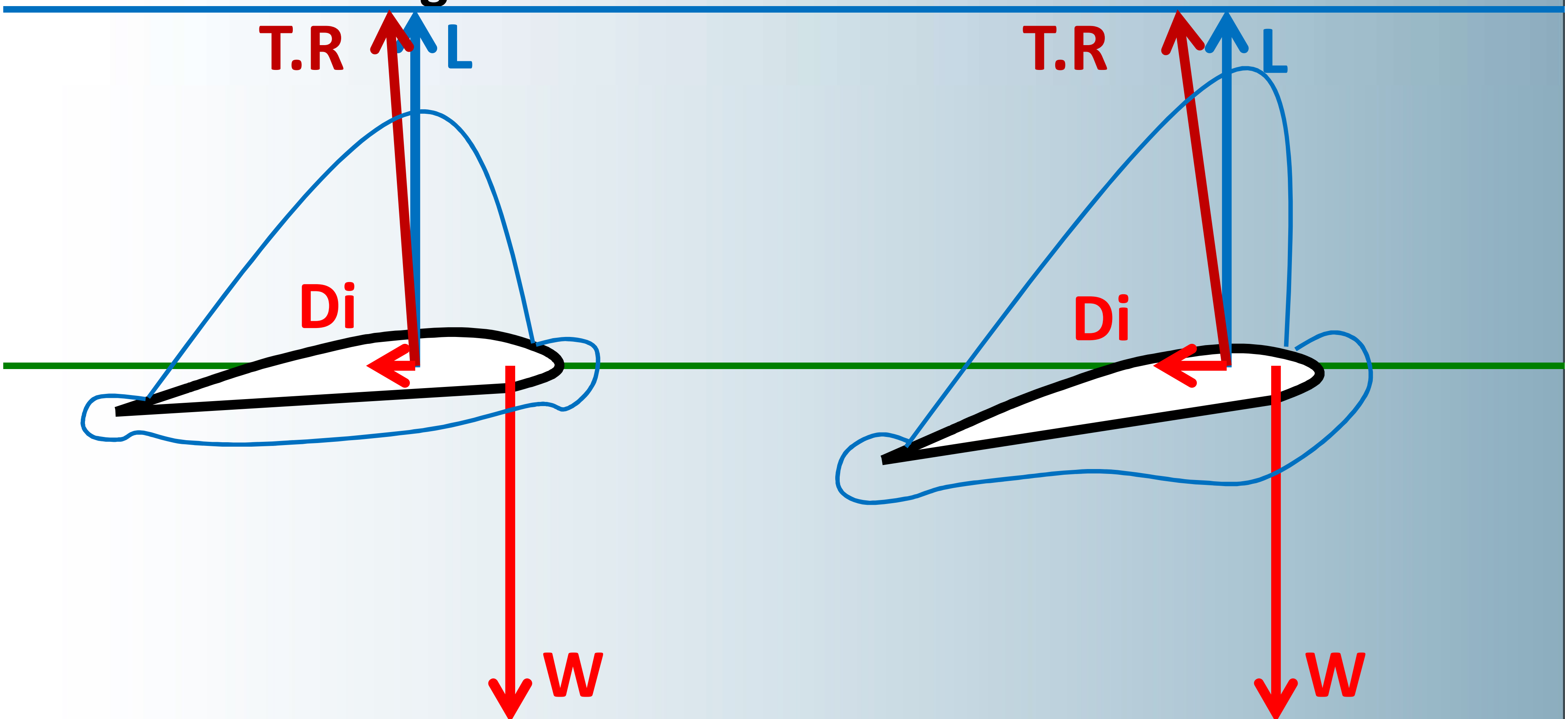
FORCES DURING A STALL

Forces during a Stall



α = 4°	α = 8°	α = 12°	α > 16°
V = 68 KIAS	V = 62 KIAS	V = 53 KIAS	V < 48 KIAS

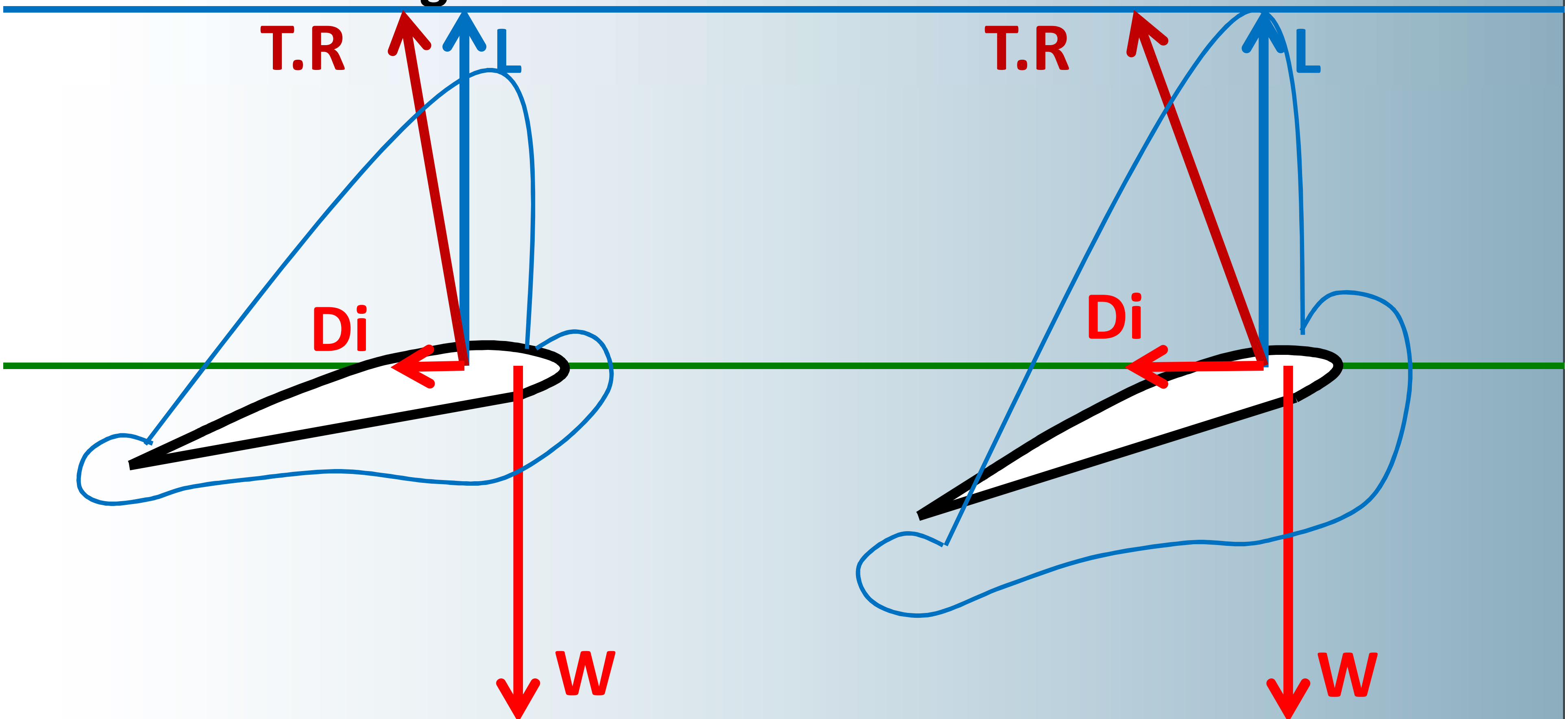
Forces during a Stall



α = 4°
V = 68 KIAS

α = 8°
V = 62 KIAS

Forces during a Stall



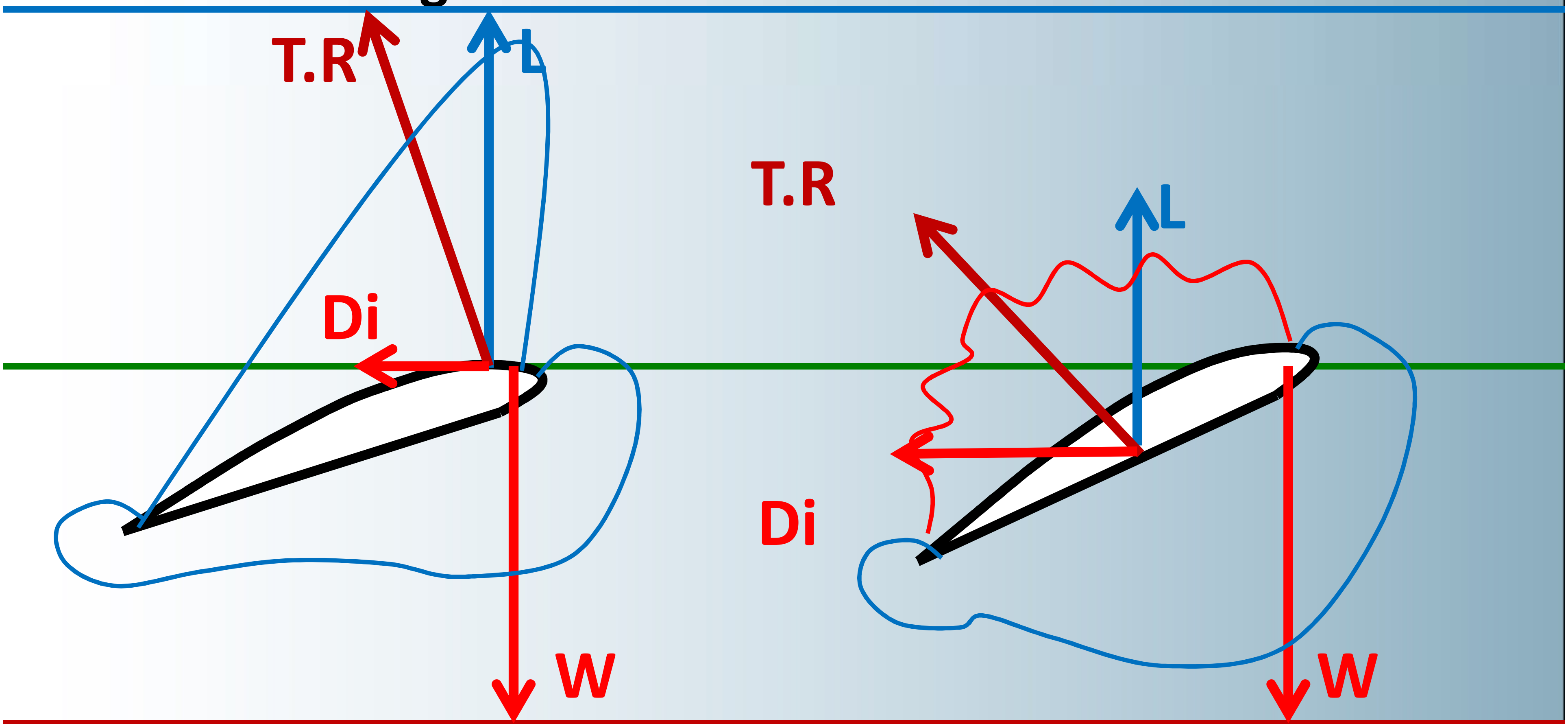
α = 8°

V = 62 KIAS

α = 12°

V = 53 KIAS

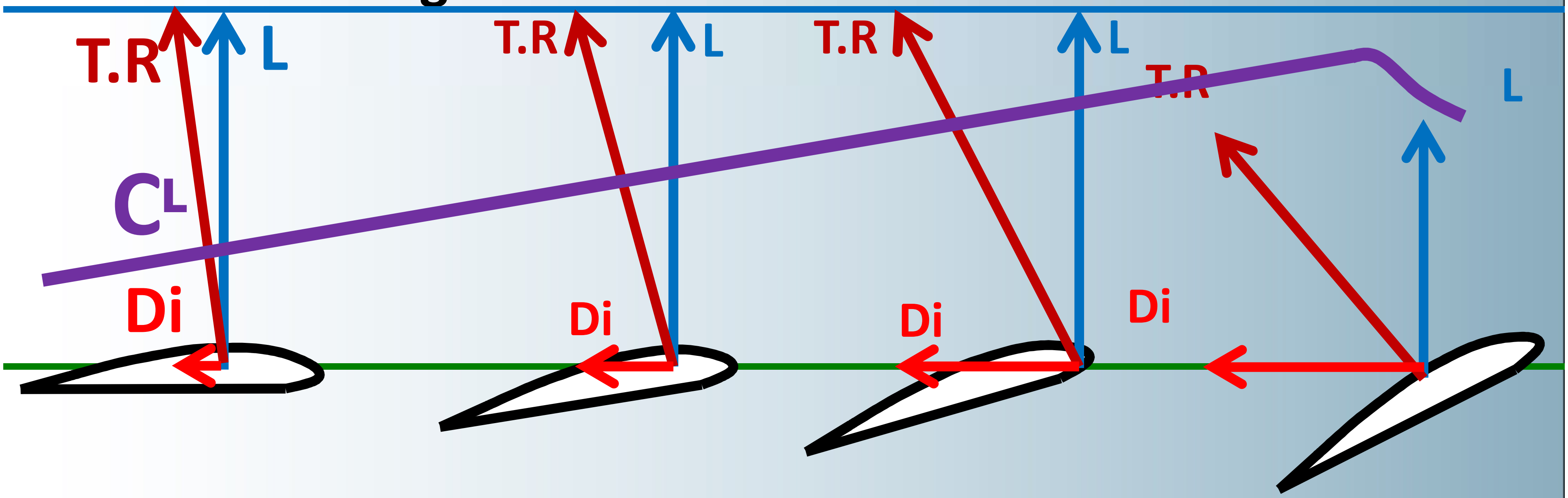
Forces during a Stall



α = 12°
V = 53 KIAS

α > 16°
V < 48 KIAS

Forces during a Stall



α = 4°
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α > 16°
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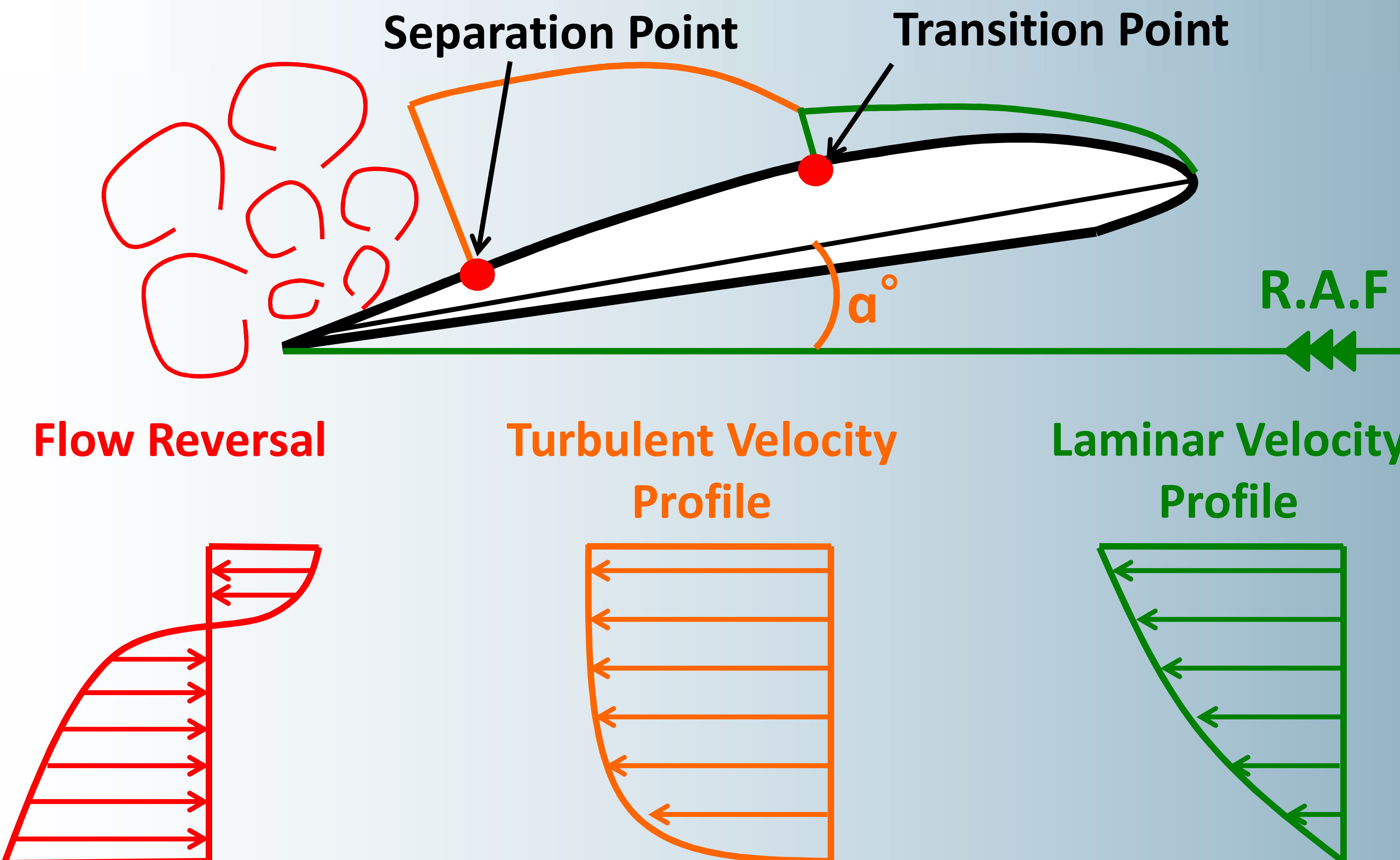
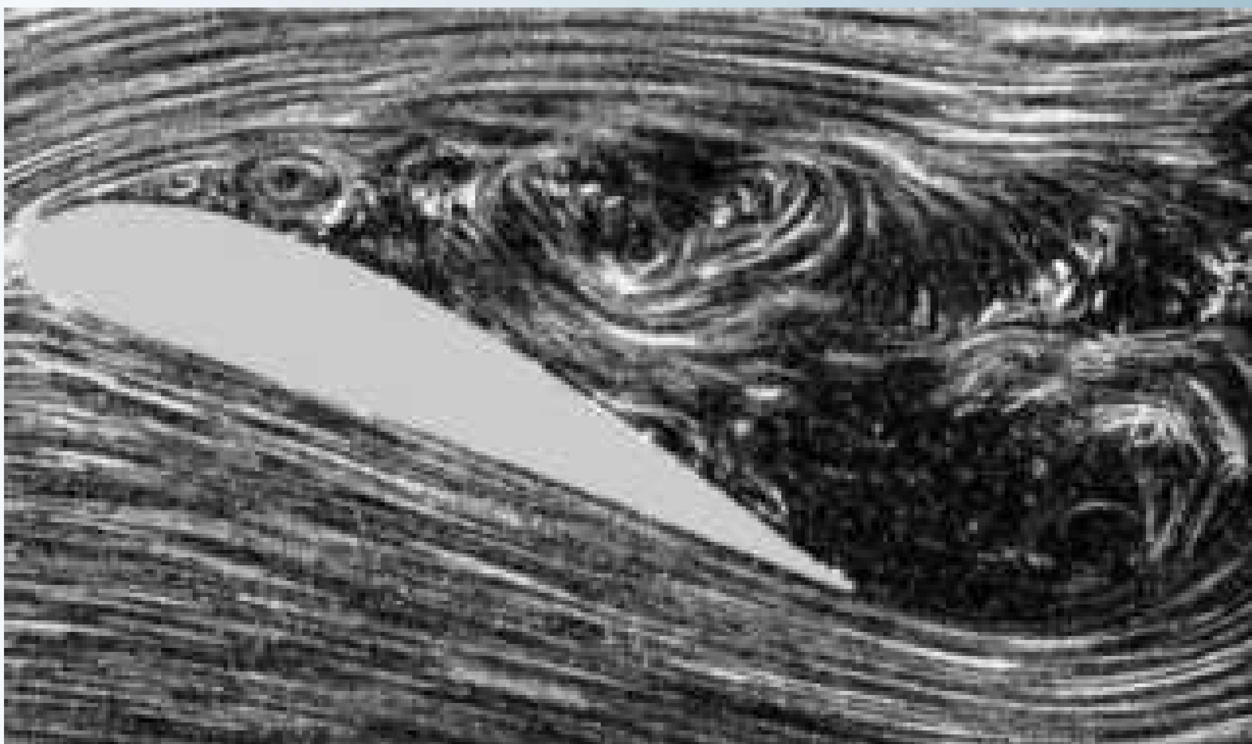
BOUNDARY LAYER

Boundary Layer



Boundary Layer

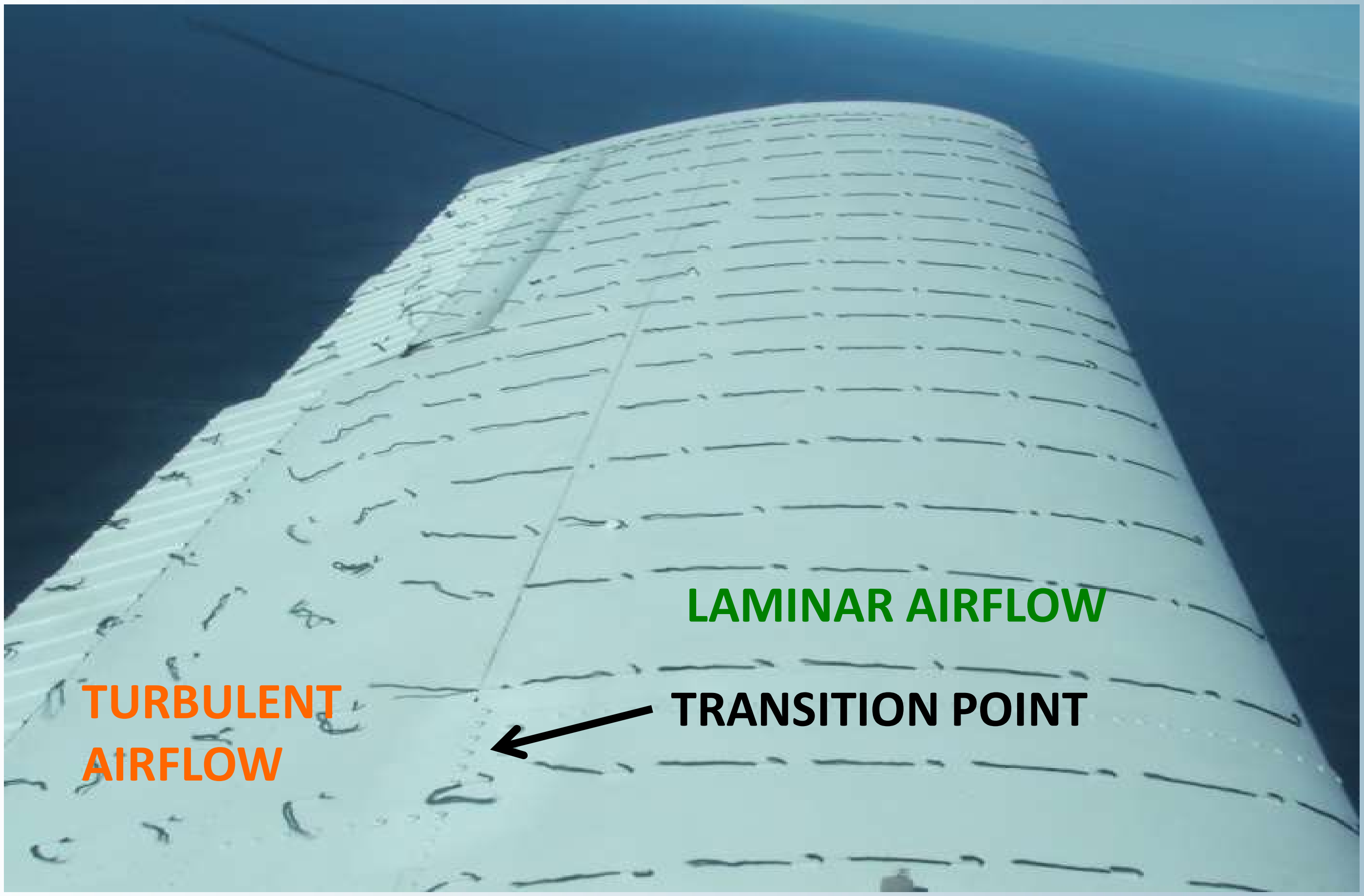


Airflow separating from an aerofoil at a high angle of attack

Boundary Layer

Streamline (laminar) flow at approximately 100 KIAS and <16° AoA

Boundary Layer



As the Angle of Attack is increased, we can see the breakdown of laminar airflow into turbulent airflow

STALL RECOGNITION AND RECOVERY

Stall Symptoms

High nose attitude:

- In level flight stalls the attitude will be high
- Maybe be a poor indicator if not in level flight or in dynamic manoeuvres

Low Airspeed:

- Classic stall symptom
- Aeroplane will stall at slow speed in level flight
- Can be stalled at much higher airspeed during manoeuvres

Stall stick position:

- At the stall the stick will usually be significantly aft

Stall Symptoms

Stall warning (if fitted):

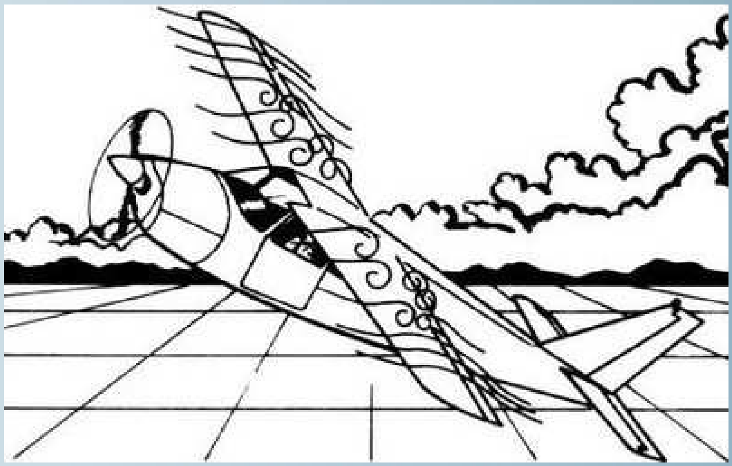
- The stall warning will activate a few knots above the stall speed
- May provide little warning during dynamic manoeuvres

Buffet:

- As the wing stalls turbulent airflow from the wing strikes the tail, causing buffeting of the airframe
- Note: C172 has little buffet

Mushy controls:

- At low airspeeds the controls feel mushy and ineffective



Stall Symptoms

Nose drop:

- As the wing stalls, the CoP moves aft suddenly, causing the nose to drop

Wing drop:

- Difficulty in controlling roll, a wing drop may occur

Inability to stop descent:

- With weight now greater than lift, the aircraft will descend despite nose up input

FACTORS AFFECTING STALL SPEED

Stall Speed

“The speed below which an aeroplane will stall”

Stall Speed

"The speed below which an aeroplane will stall"

	Stall Speed (Vs)
Weight ↑	
Altitude ↑	
Power ↑	
Angle of Bank ↑	
Flap ↘	
CoG Position (forward)	

Weight

- A **heavier aircraft** will require **more lift** to fly straight and level (to balance the increase in weight)
- To achieve this extra lift, **it must fly at a greater angle of attack** for any given airspeed
- This means that for any given airspeed, **there is a smaller buffer** between the actual angle of attack and the stalling angle
- If the angle of attack is increased from this greater angle, it will reach the critical angle sooner i.e. at a higher airspeed
- **Therefore, an increase in weight increases the stall speed**

Stall Speed

“The speed below which an aeroplane will stall”

	Stall Speed (Vs)
Weight ↑	↑
Altitude ↑	
Power ↑	
Angle of Bank ↑	
Flap ↘	
CoG Position (forward)	

Altitude

- As altitude increases, the air is less dense
- This means the aircraft will produce less lift
- In order to increase lift (to maintain straight and level), we require a higher angle of attack. This would mean once again, we have a reduced buffer from the critical angle and hence stall speed increases
- However, this is only true for TAS!

$$L = C_L \tfrac{1}{2} \rho v^2 S$$

- To maintain lift (straight and level) with a decreasing air density, v (true airspeed) must increase. Thus, at higher altitudes, our TAS increases whilst our IAS remains the same
- **Vs refers to IAS, and this does not change with altitude**

Stall Speed

“The speed below which an aeroplane will stall”

	Stall Speed (Vs)
Weight ↑	↑
Altitude ↑	=
Power ↑	
Angle of Bank ↑	
Flap ↘	
CoG Position (forward)	

Power

- An increase in power would increase the thrust force of the propeller
- During a stall entry with a high nose attitude, the thrust force would have a vertical component that helps to balance weight
- Therefore, **power reduces the stall speed**
- An increase in power also increases the slipstream
- This increases the airflow over the inner section of the wings which may delay the stall
- However, the slipstream will not reach the wingtips so if a stall does occur, a wing drop may occur

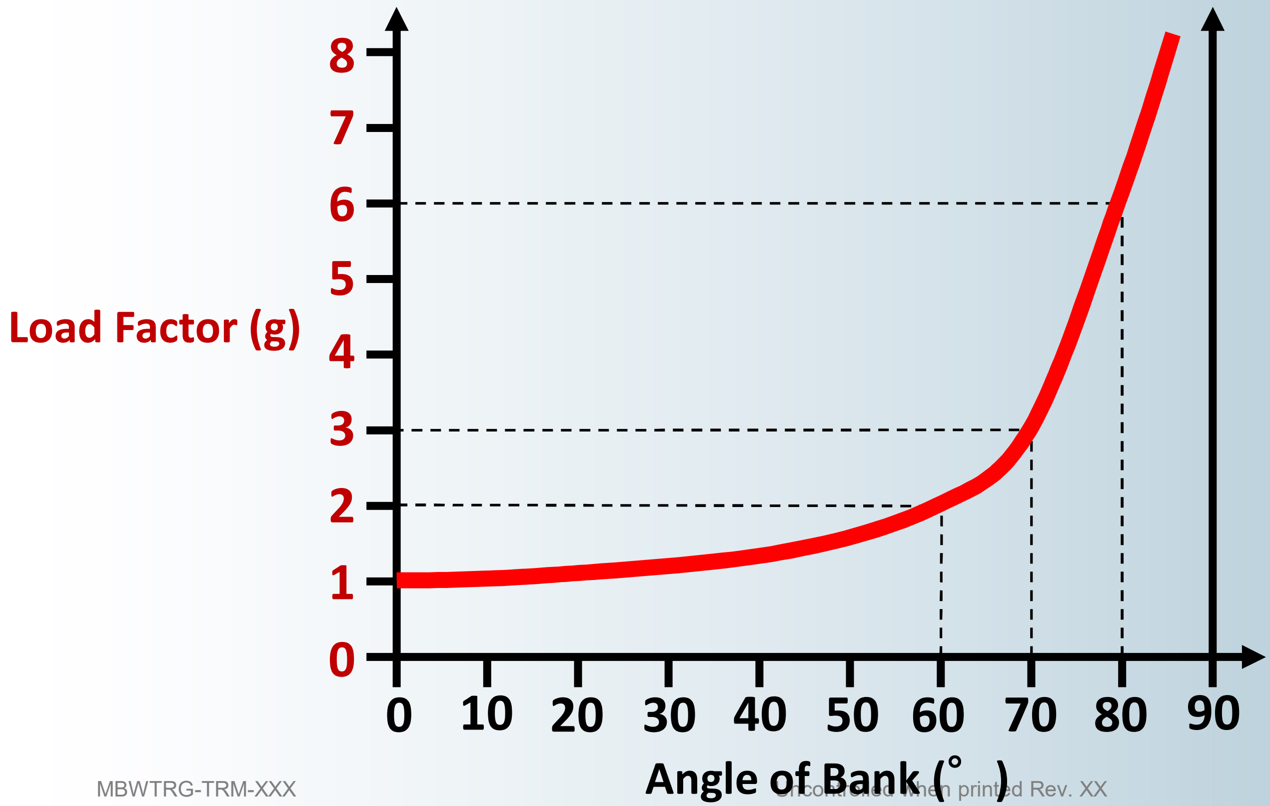
Stall Speed

“The speed below which an aeroplane will stall”

	Stall Speed (Vs)
Weight ↑	↑
Altitude ↑	=
Power ↑	↓
Angle of Bank ↑	
Flap ↘	
CoG Position (forward)	

Angle of Bank

- When an aeroplane is banked, its load factor or "g" load increases
- This has the same effect as an increase in weight
- **An increase in Angle of Bank increases the stall speed**



Angle of Bank	Vs Increase (%)
30	7%
45	19%
60	41%
75	100%

Angle of Bank

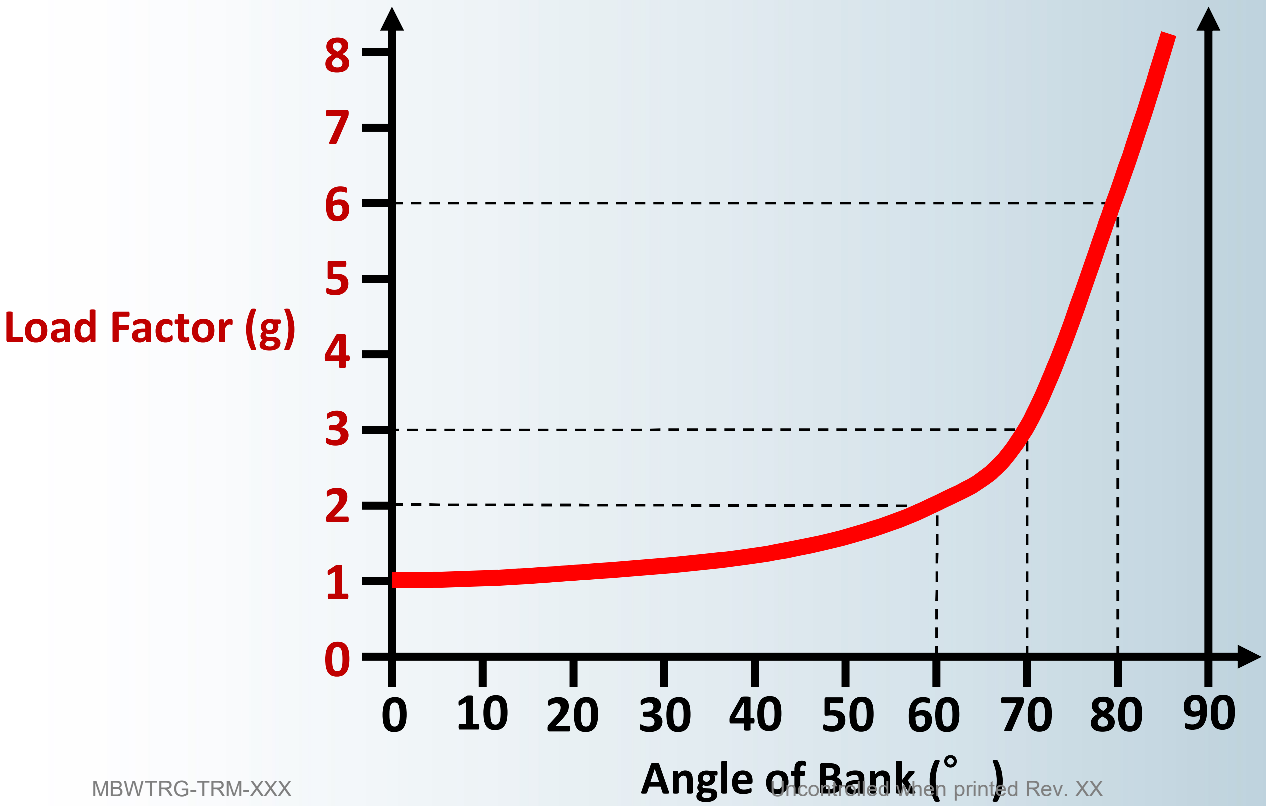
$V_{SI} = VS \times \sqrt{LF}$

E.g. 60° Level Turn

$V_{SI} = 48 \times \sqrt{2}$

$V_{SI} = 48 \times 1.4$ *(i.e. an increase of 40%)*

$V_{SI} = 68\text{kts}$



Angle of Bank	Vs Increase (%)
30	7%
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75	100%

Stall Speed

“The speed below which an aeroplane will stall”

	Stall Speed (Vs)
Weight ↑	↑
Altitude ↑	=
Power ↑	↓
Angle of Bank ↑	↑
Flap	
CoG Position (forward)	

Flap

- Flaps increase both lift and drag

- The increase in drag slows the aircraft down whilst the increase in lift allows the nose attitude to be lowered (reduction in angle of attack)

- There is now a greater buffer between the actual angle of attack and the critical angle

- **Therefore, flaps reduce the stall speed**

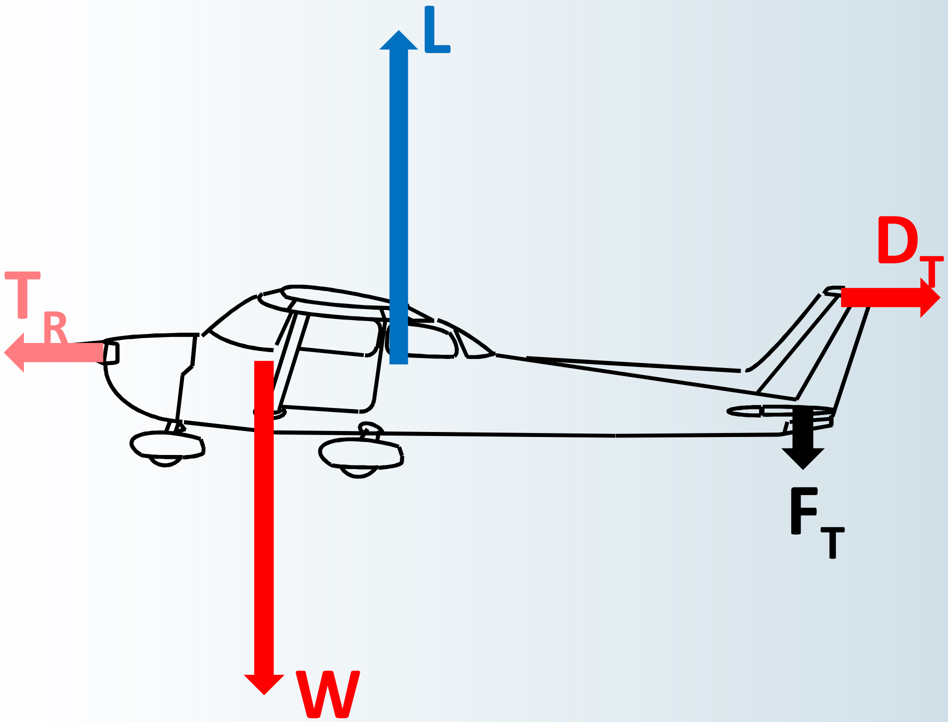
Stall Speed

“The speed below which an aeroplane will stall”

	Stall Speed (Vs)
Weight ↑	↑
Altitude ↑	=
Power ↑	↓
Angle of Bank ↑	↑
Flap ↘	↓
CoG Position (forward)	

Forward Centre of Gravity

- If the CoG is moved forward, then the downwards force provided by the tailplane will increase in order to maintain straight and level flight



- If this occurs, then the force required will increase
- This is achieved through increasing the angle of attack
- Once again, there is now a smaller buffer between the actual angle of attack and the critical angle
- **Therefore, a forward CoG will increase the stall speed**

Stall Speed

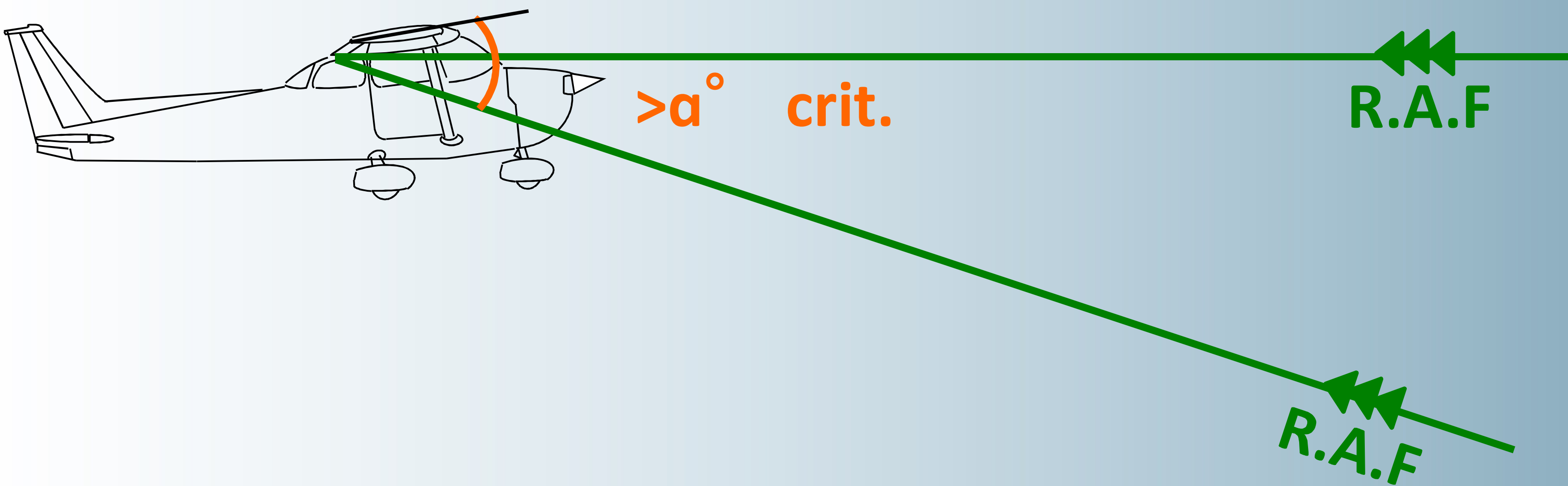
“The speed below which an aeroplane will stall”

	Stall Speed (Vs)
Weight ↑	↑
Altitude ↑	=
Power ↑	↓
Angle of Bank ↑	↑
Flap ↘	↓
CoG Position (forward)	↑

EFFECT OF WIND SHEAR/VERTICAL GUSTS

Wind Shear/Vertical Gusts

- A stall could occur even without raising the nose of the aircraft



- If wind shear or gusting winds cause the relative airflow to change, then the critical angle could be exceeded without any pilot error whatsoever!

- In this situation, the critical angle appears to have decrease but remember, the angle has stayed the same but the relative airflow has changed

EFFECT OF FROST/ICE

Frost and Ice

- Normally, the critical angle will remain the same and only the stall speed will change

- **However, there is one situation where the critical angle will change – when an aerofoil is covered in frost and/or ice**

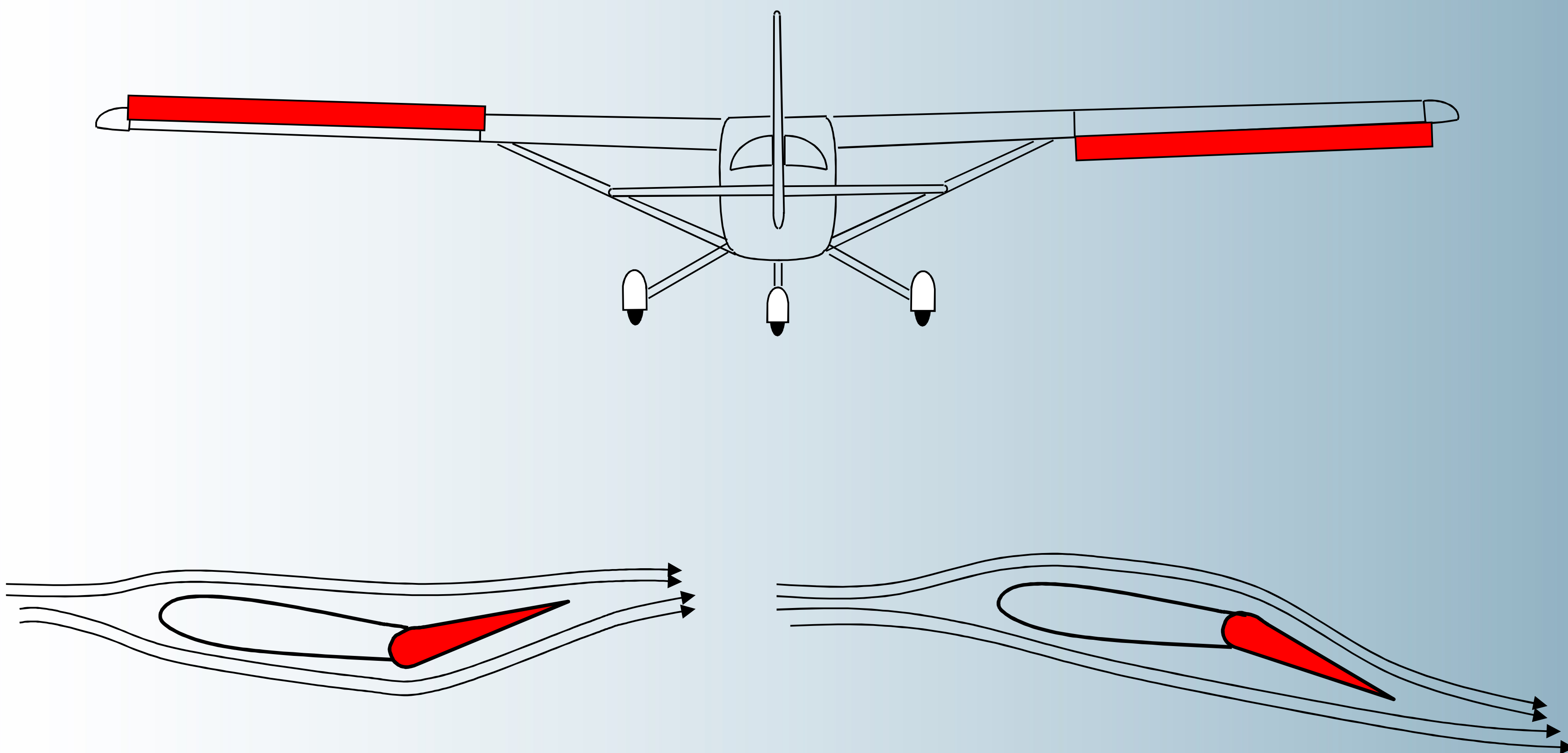
- **Also known as "hoar frost," this will decrease the critical angle and increase the stall speed**

USE OF AILERON DURING STALL RECOVERY

Use of Aileron

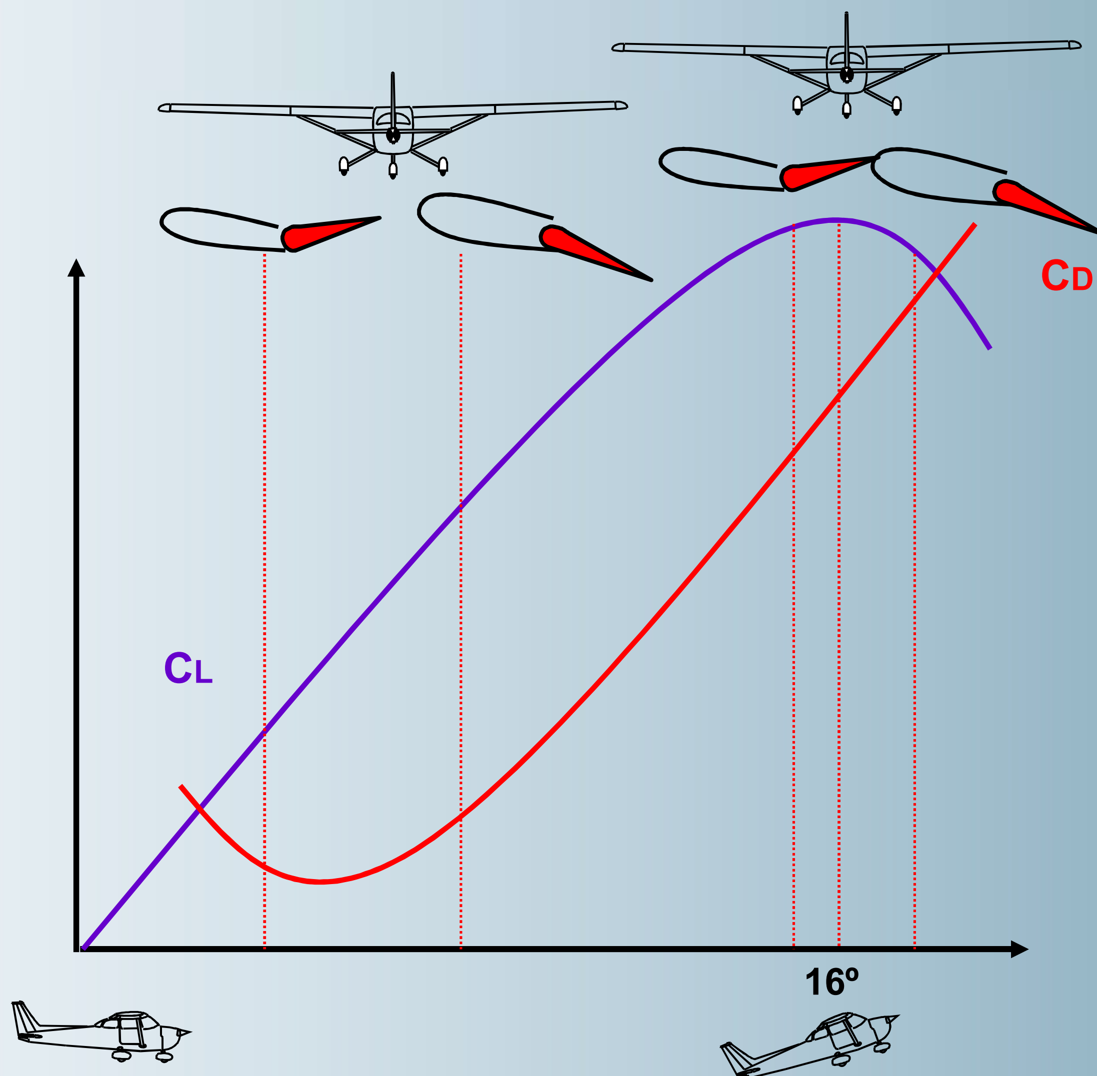
- Sometimes during a stall, you may experience a “wing drop” where one wing rapidly falls away causing roll

- This occurs when one wing stalls before the other (the stalled wing drops)



Use of Aileron

- To avoid any further stalling of the wings, rudder should be the primary control used to level the wings
- If ailerons are used first, then the aircraft may enter an accidental spin…



STALL PATTERNS

Stall Patterns

The shape of the wing will influence the way it stalls:

Rectangular straight wings:

- Tend to stall at the root first and spread outwards
- Generally good handling characteristics
- Good aileron control
- Good stall symptoms
- Nose down at the stall

Swept back wings:

- Tend to stall at the tips first and spread inwards
- Poor handling characteristics
- Can cause wing drop
- Can cause pitch up because CoP moves forward which makes the stall worse

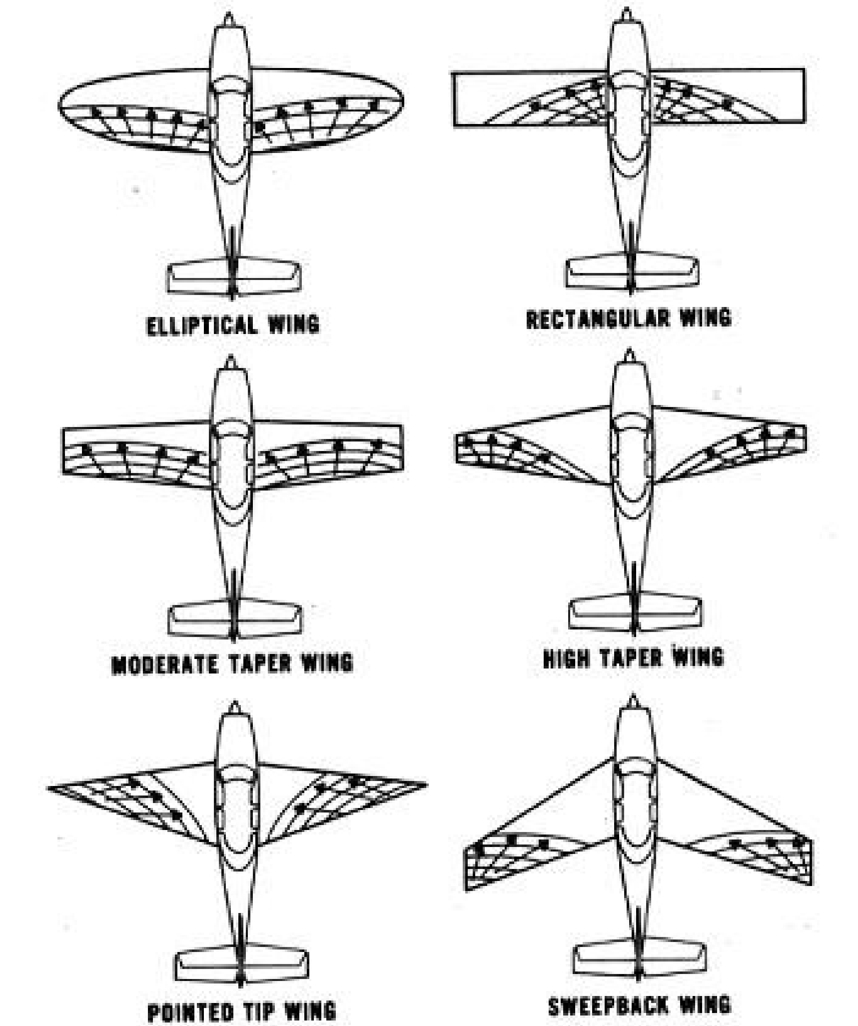


Figure 17–13 Wing Planforms (Exaggerated)

Modifying Stall Patterns

Several methods are available to aircraft designers to improve the handling characteristics of an aircraft during a stall, they include:

- **Washout**
- **Stall Strips**
- **Vortex generators**
- **Wing fences**

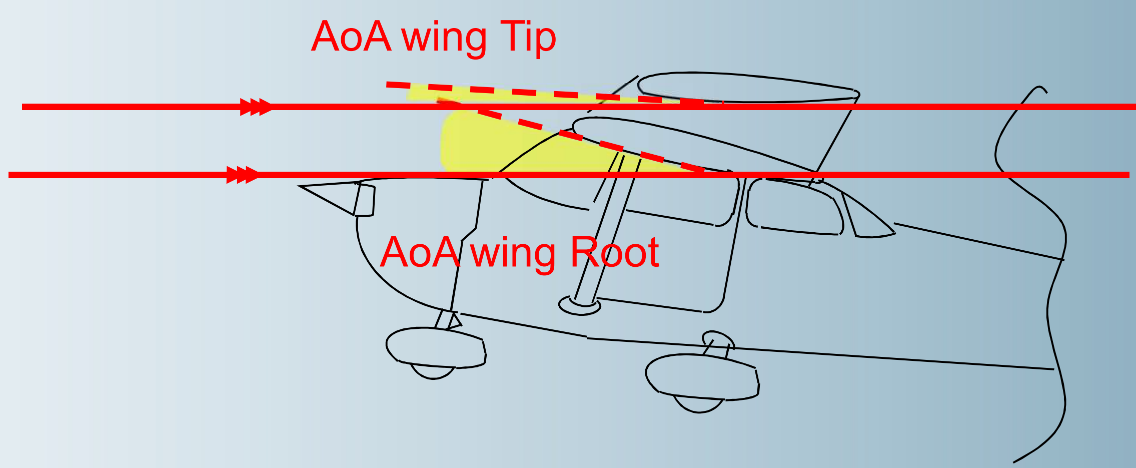
Wing Washout

Wing washout involves designing the wing so it has a lower angle of incidence at the tip than at the root.

The Root then has a higher AoA than the tip and should stall first, ensuring the best possible handling characteristics

This gives:

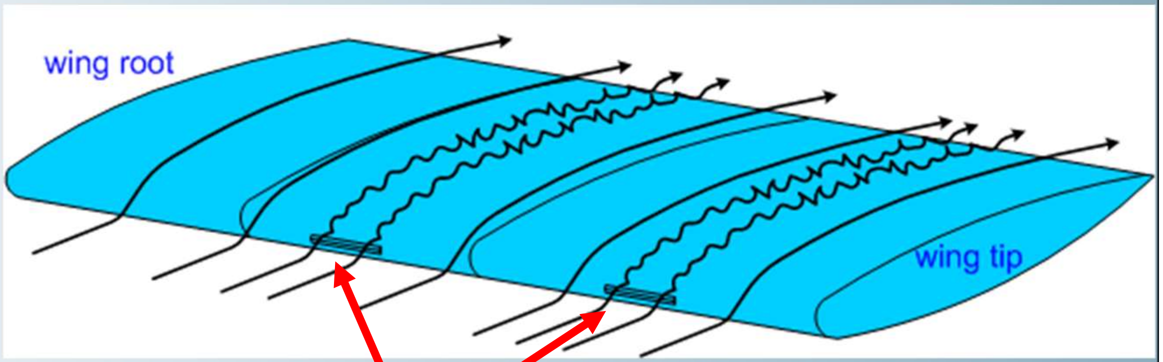
- Better aileron control approaching the stall
- Early buffeting of the tail, good stall warning
- Reduced chance of a wing drop



Stall Strips

Stall strips are sharp edges strategically placed on the wing leading edge to cause certain parts to stall before others

- They work by intentionally stalling the section of wing behind them at a lower AoA than the rest of the wing
- They can be used to give the same effects as washout when placed near the wing root

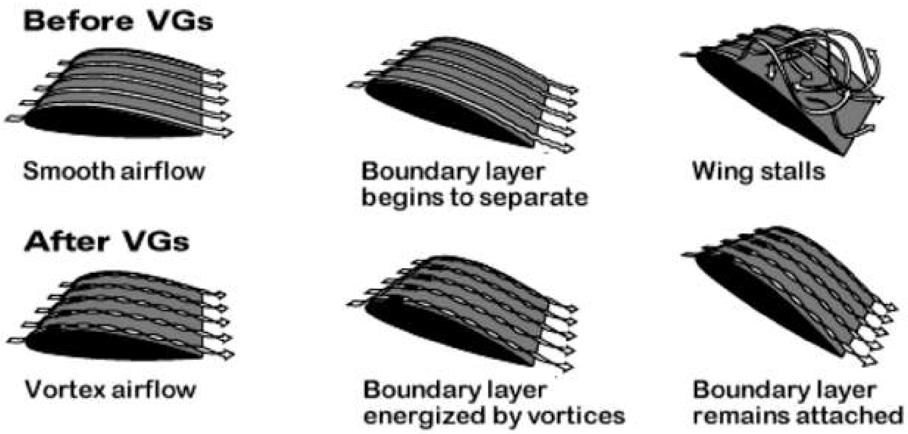


Stall Strips

Vortex Generators

Vortex generators are small surfaces placed on the wing's upper leading edge to delay the stall

- They work by creating a series of stable vortices along the upper surface of the wing
- The vortices re-energise the airflow, delaying separation and stall
- Can increase stall AOA and reduce stall speed
- Can increase control effectiveness
- They can be used to give the same effects as washout when placed near the wing tips

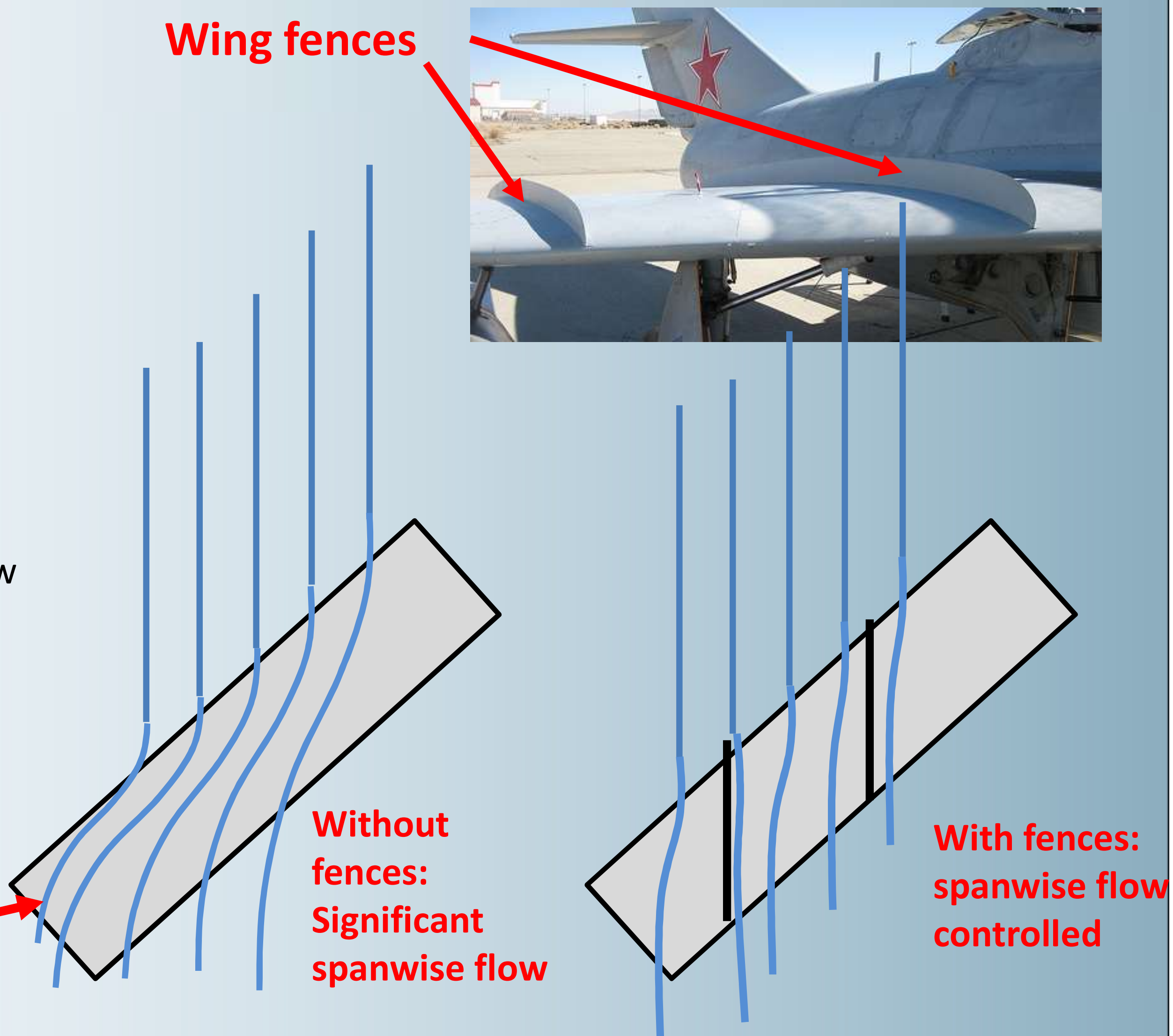


By energizing the boundary layer, VGs allow the airfoil to operate at higher angles-of-attack without airflow separation.
(Copyright Micro AeroDynamics)

Wing Fences

Wing fences are vertical surfaces which run along the chord of the wing

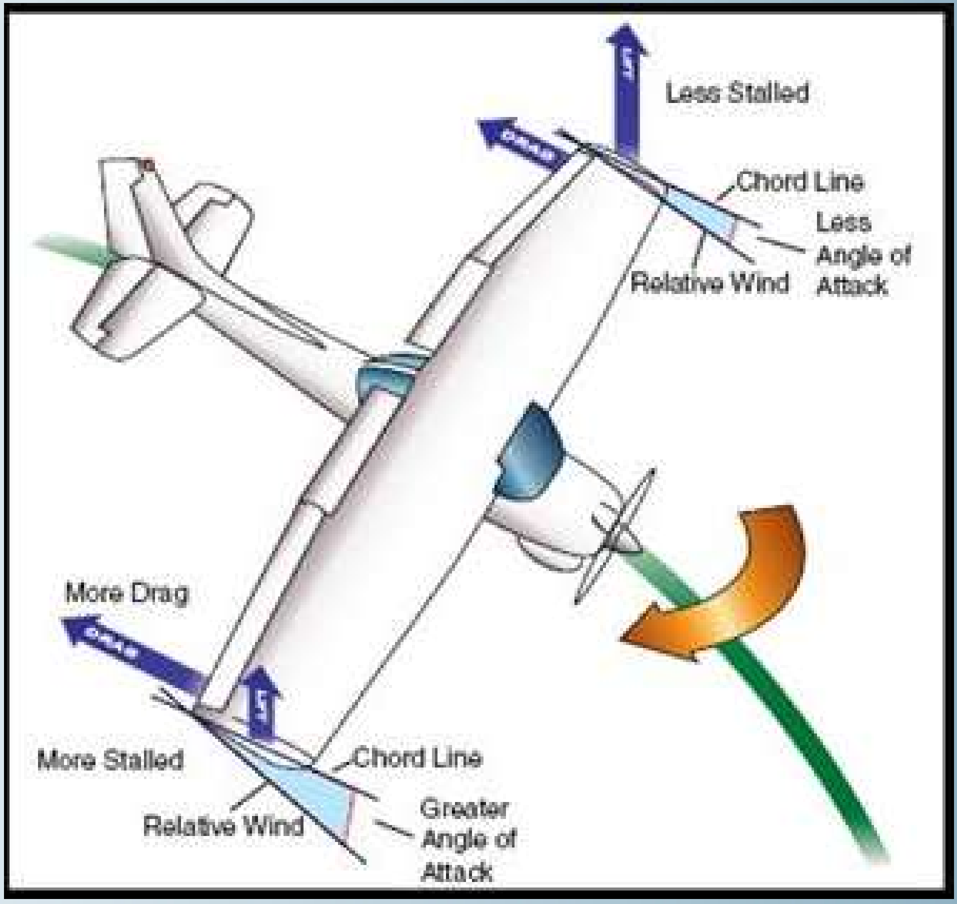
- Generally seen on swept wing aircraft
- Span-wise flow of the air can cause the wing tips to stall first
- Fences minimise span-wise flow
- Fences will generally improve handling characteristics



SPINS AND SPIRAL DIVES

Spin Entry

- A spin occurs when one wing stalls MORE than the other wing
- This may occur if you stall in uncoordinated flight
- The wing which stalls more will have less lift and more drag, causing the aircraft to roll and yaw towards the more stalled wing
- As the more stalled wing drops, the relative airflow changes and the AOA increases, stalling the wing even more
- This sets up an increasing, and eventually stable rotation called “autorotation”



Spins

In a spin the aircraft will “Auto-rotate” and descend helically around an axis known as the *spin axis*

Incipient stage:

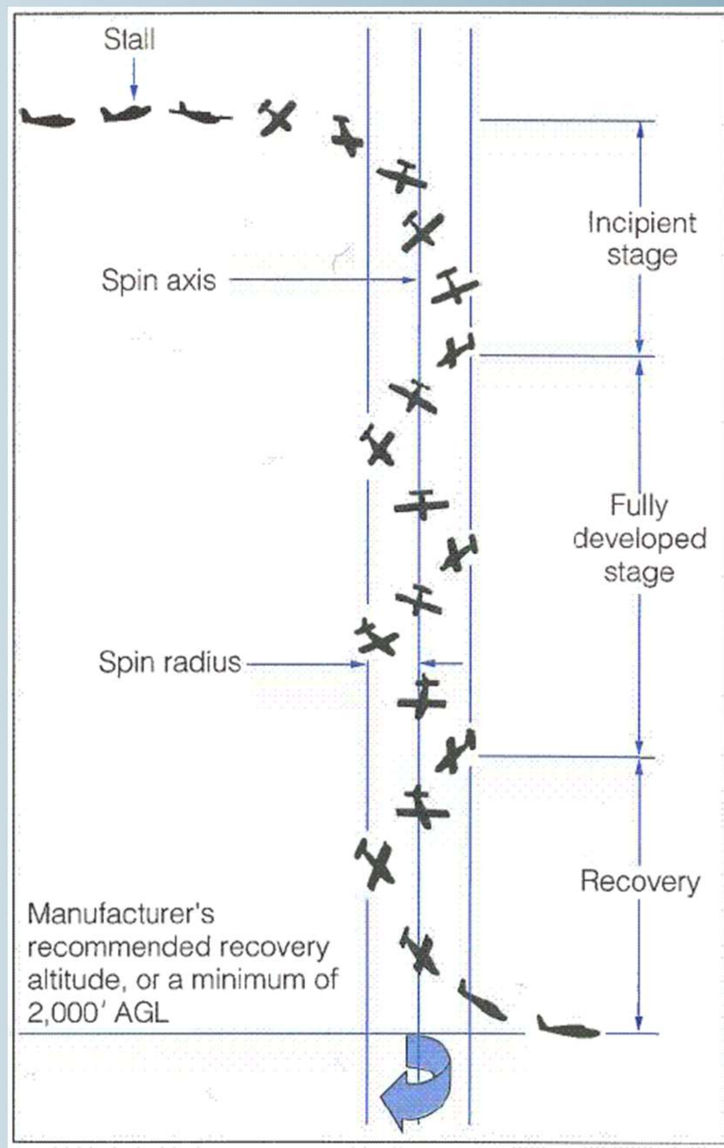
- The incipient stage is the first stage of a spin and begins as one wing drops and ends when the spin is stabilised
- Usually lasts about 1-3 rotations

Fully developed stage:

- The spin is stable
- Usually this stage will last until recovery efforts begin (or ground impact)

Recovery stage:

- The rotation is arrested and the wings are un-stalled
- Aircraft must now recover from steep nose down attitude



CADA 6 – Stalling, Spinning and Spiral Dives

Spin

- A condition of stalled flight
- Roll causing yaw causing roll causing yaw etc. (known as "autorotation")
- Motion is helical around a vertical axis
- Stable:

  1. Low and steady airspeed
  2. Steady rate of descent
  3. Low g-forces

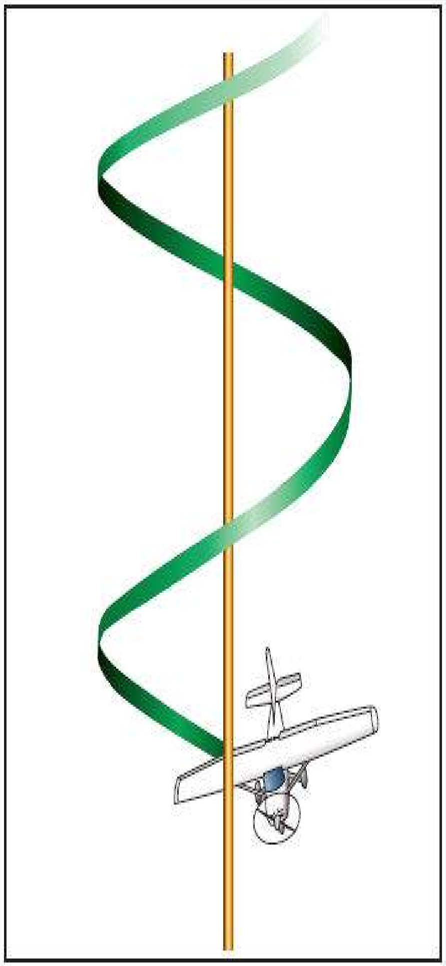
Spiral Dive

- Not stalled – "a steep turn gone wrong"
- Rolling and yawing occurs but not autorotation
- Unstable:

  1. High and increasing airspeed
  2. High and increasing rate of descent
  3. High g-forces

CADA 6 – Stalling, Spinning and Spiral Dives

Spin



Spiral Dive

Stall/Spin Recovery

There are multiple different stall recovery techniques, they vary between aircraft types and given situations, however the overall goal is always the same:

REDUCE AOA TO BELOW THE CRITICAL AOA

Stall/Spin Recovery

The generic **stall recovery** procedure used in most light aircraft is as follows:

1. **Relax back pressure** to reduce AOA (This alone should un-stall the wing)
2. **Smoothly add full power** to increase airspeed
3. **Maintain directional control with the rudder (DO NOT use aileron until un-stalled)**

The generic **Spin/Incipient recovery** procedure used in most light aircraft is as follows:

1. **Power to IDLE** to remove any unwanted gyroscopic effects or pitching moments
2. **Ailerons NEUTRAL** to avoid aggravating the spin
3. **Rudder FULL OPPOSITE to the direction of rotation** to slow rotation
4. **Elevator FORWARD** to reduce AOA and break the stall

CAE Oxford Aviation Academy

Stalls and Spins

https://www.youtube.com/watch?v=MIjmMi7XN4M

C172 doing some stalls and spins

https://www.youtube.com/watch?v=FzUakyCFYSc

Fokker 70 doing some stalls and an incipient spin (Spin unintentional)