CPL Theory
Aerodynamics (CADA)

CAE Oxford
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CADA 5 – Climbing and Descending

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2. Related Documents

Related Documents	Document Identification

CADA 5 – Climbing and Descending

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.

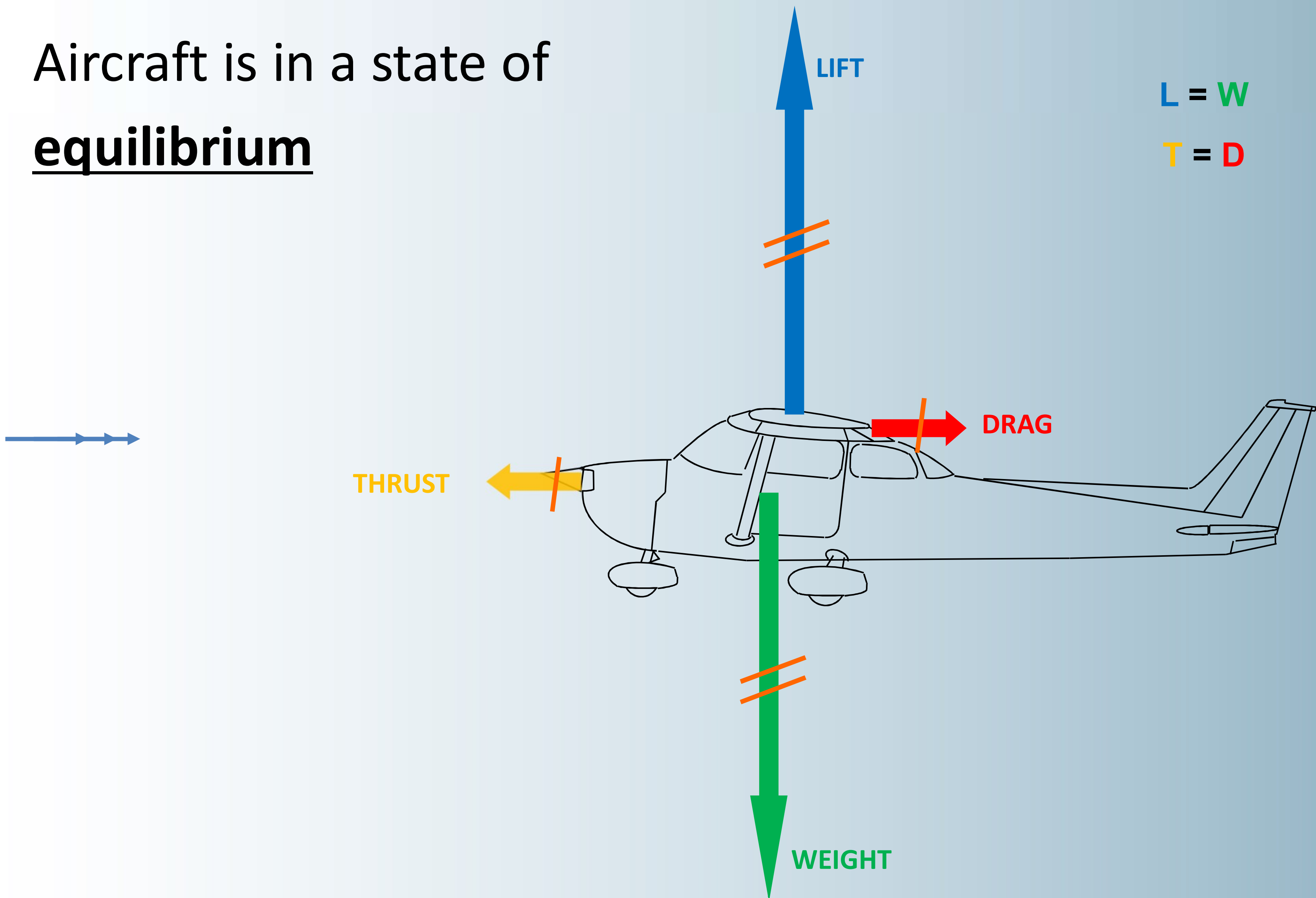
Slide	Changes

FORCES IN STRAIGHT AND LEVEL

CADA 5 – Climbing and Descending

Aircraft is in a state of

<u>equilibrium</u>



FORCES IN A STEADY CLIMB

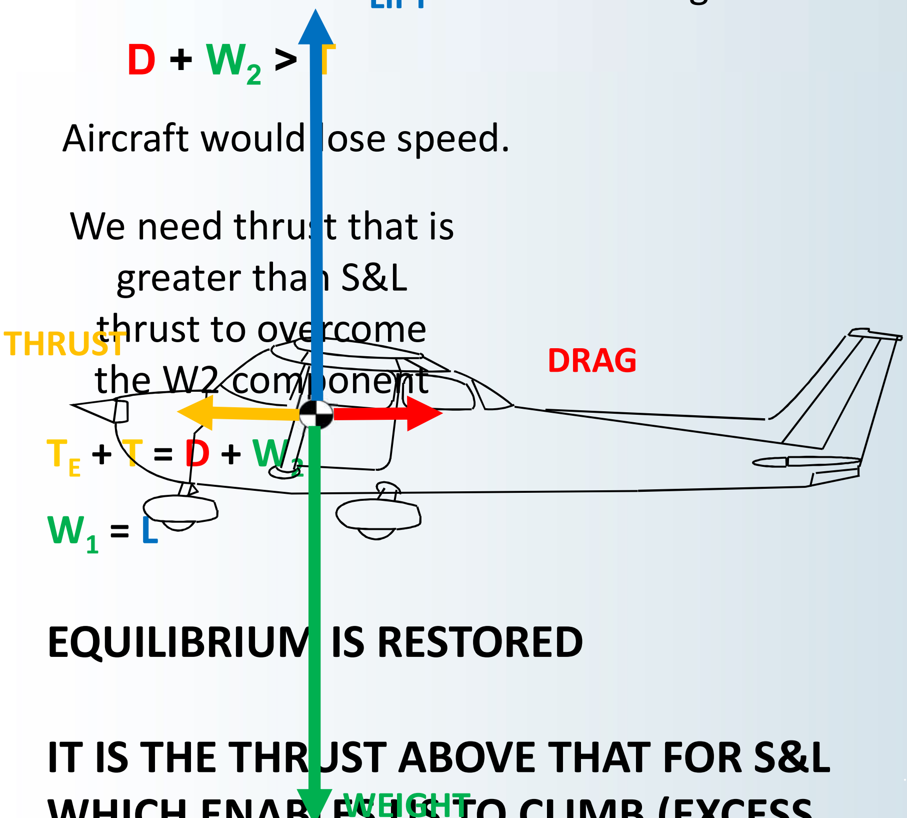
CADA 5 – Climbing and Descending

W2 acts in the same direction as drag.

$D + W_2 > T$

Aircraft would lose speed.

We need thrust that is greater than S&L thrust to overcome the W2 component

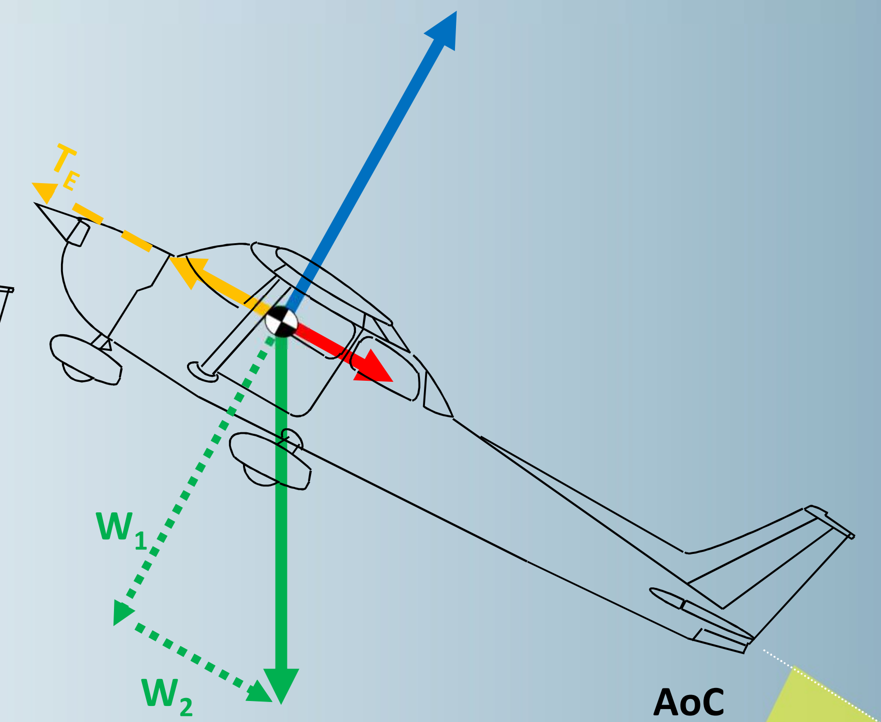


$T_E + T = D + W_2$

$W_1 = L$

EQUILIBRIUM IS RESTORED

IT IS THE THRUST ABOVE THAT FOR S&L WHICH ENABLES US TO CLIMB (EXCESS THRUST)



However;

$T > D \qquad L < W$

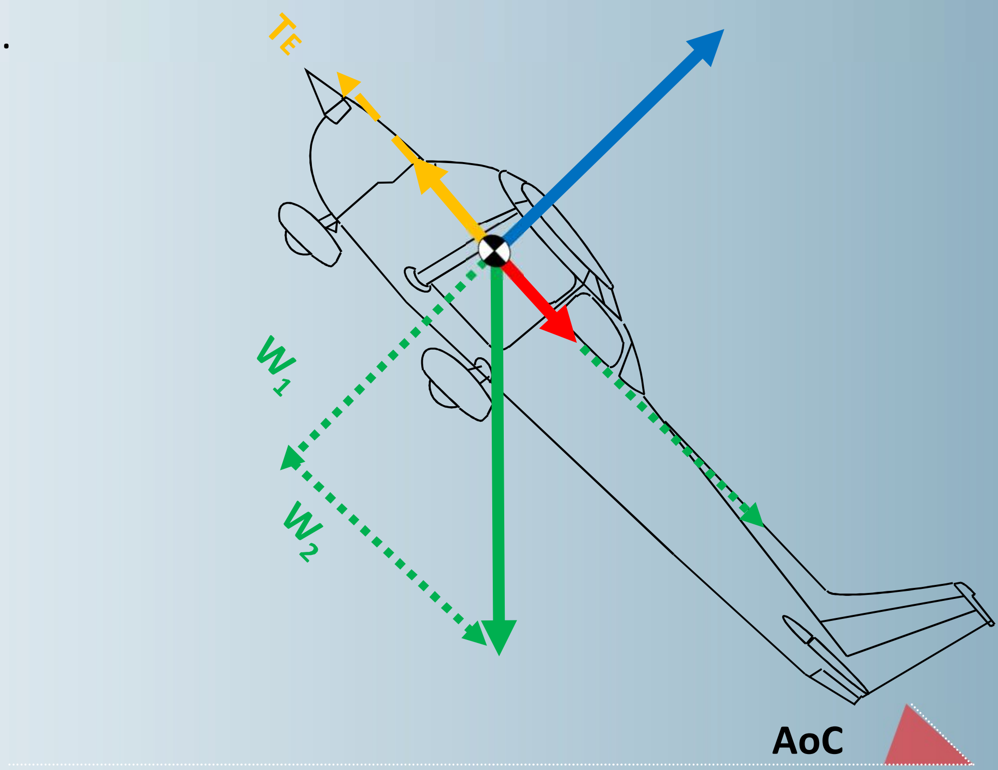
CADA 5 – Climbing and Descending

Greater component of W2 acts with drag.

$D + W_2 > T$

To maintain speed we need more excess thrust to balance out W_2

The amount of thrust available from the engine is fixed, therefore AoC has a **LIMIT**



$\uparrow T_E = \uparrow AoC$

TYPES OF CLIMBS

Types of Climbs

Best Angle of Climb:

- Maximum vertical distance for the minimum amount of horizontal distance
- Achieved by flying at the speed for Maximum Excess Thrust (62 knots in C172)
- Used for obstacle clearance at low level i.e. take-off

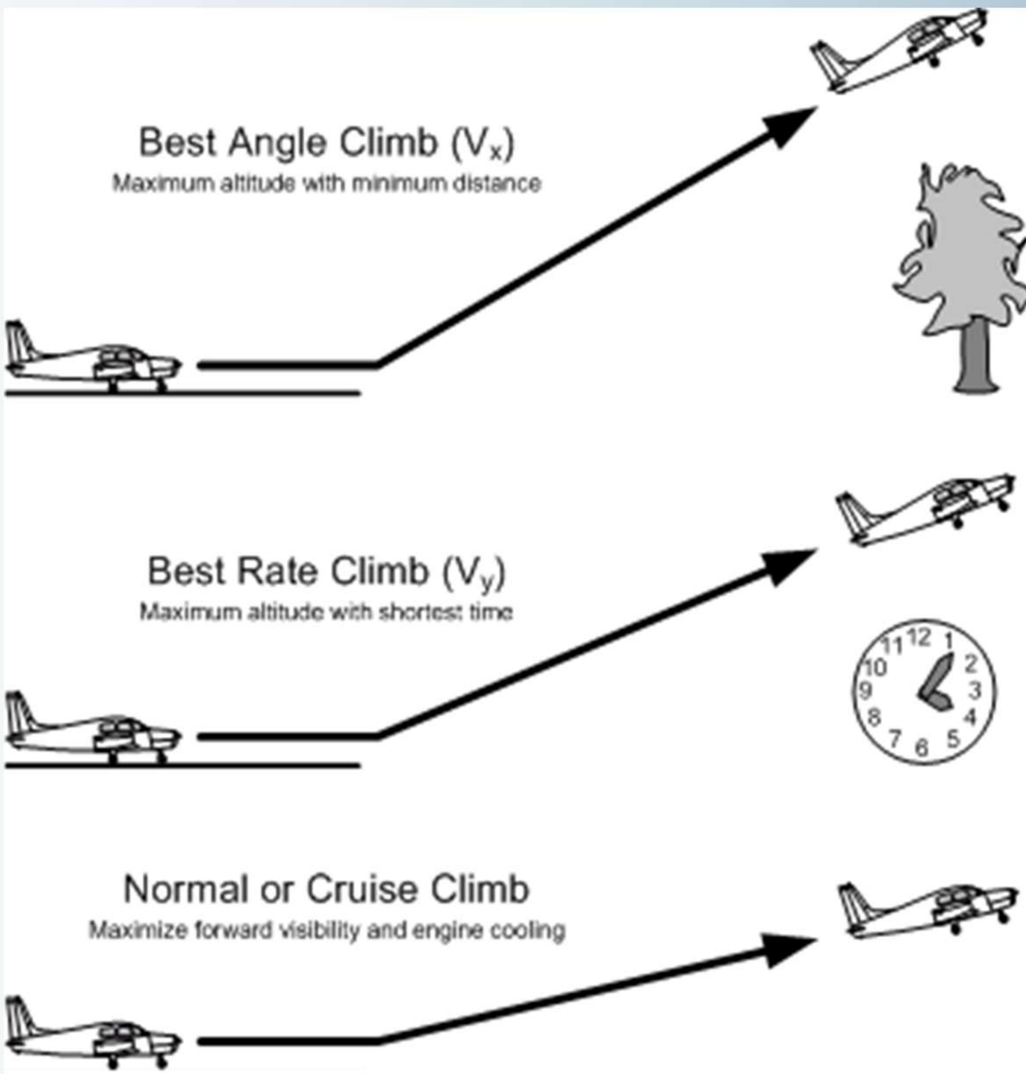
Best Rate of Climb:

- Maximum vertical distance for the minimum amount of time
- Achieved by flying at the speed for Maximum Excess Power (74 knots in C172)
- Common in flight training sorties

Cruise Climb:

- Lowest rate of climb but best forward speed
- Better forward visibility & better engine cooling

Types of Climbs



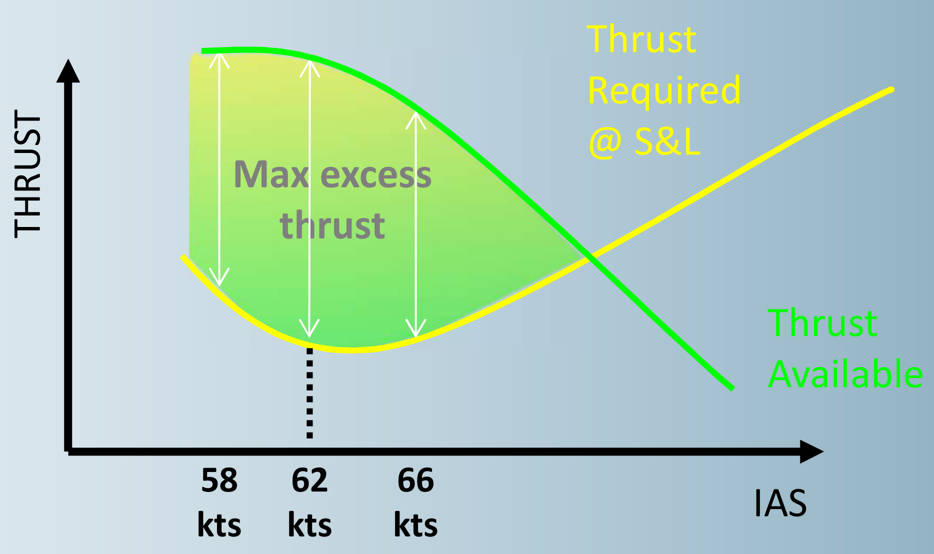
BAoC (V_X)

The thrust above what is required for S&L (i.e. Excess Thrust or T_E) is available to climb the aircraft.

Maximum excess thrust gives BAoC

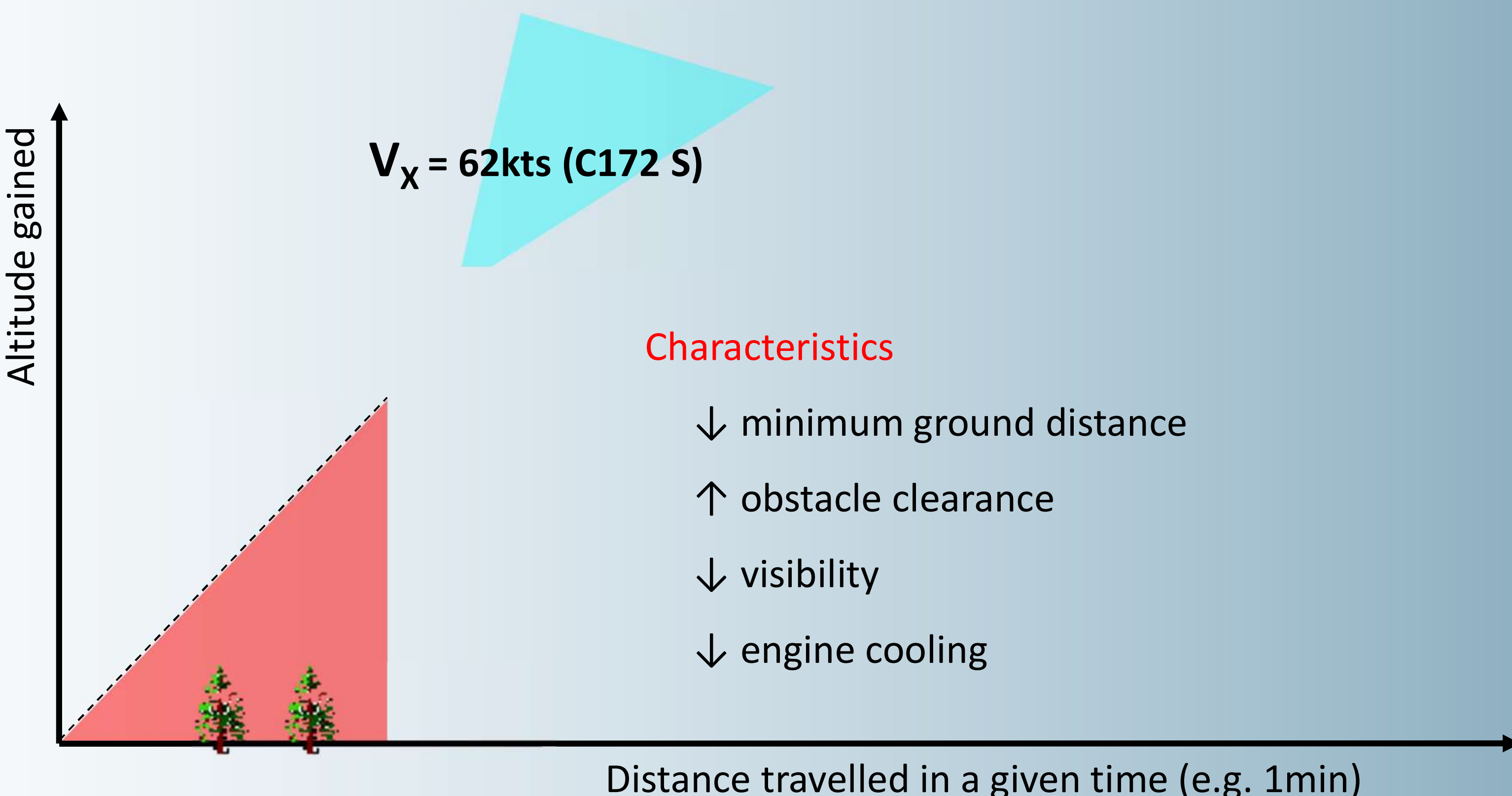
BAoC (V_X)(C172 S) = 62kts

A decrease or increase in airspeed, decreases the amount of excess thrust, reducing our AoC



BAoC (V_X)

Best Angle of Climb (V_X) = $\dfrac{\text{Altitude gain}}{\text{Min distance}}$



Characteristics

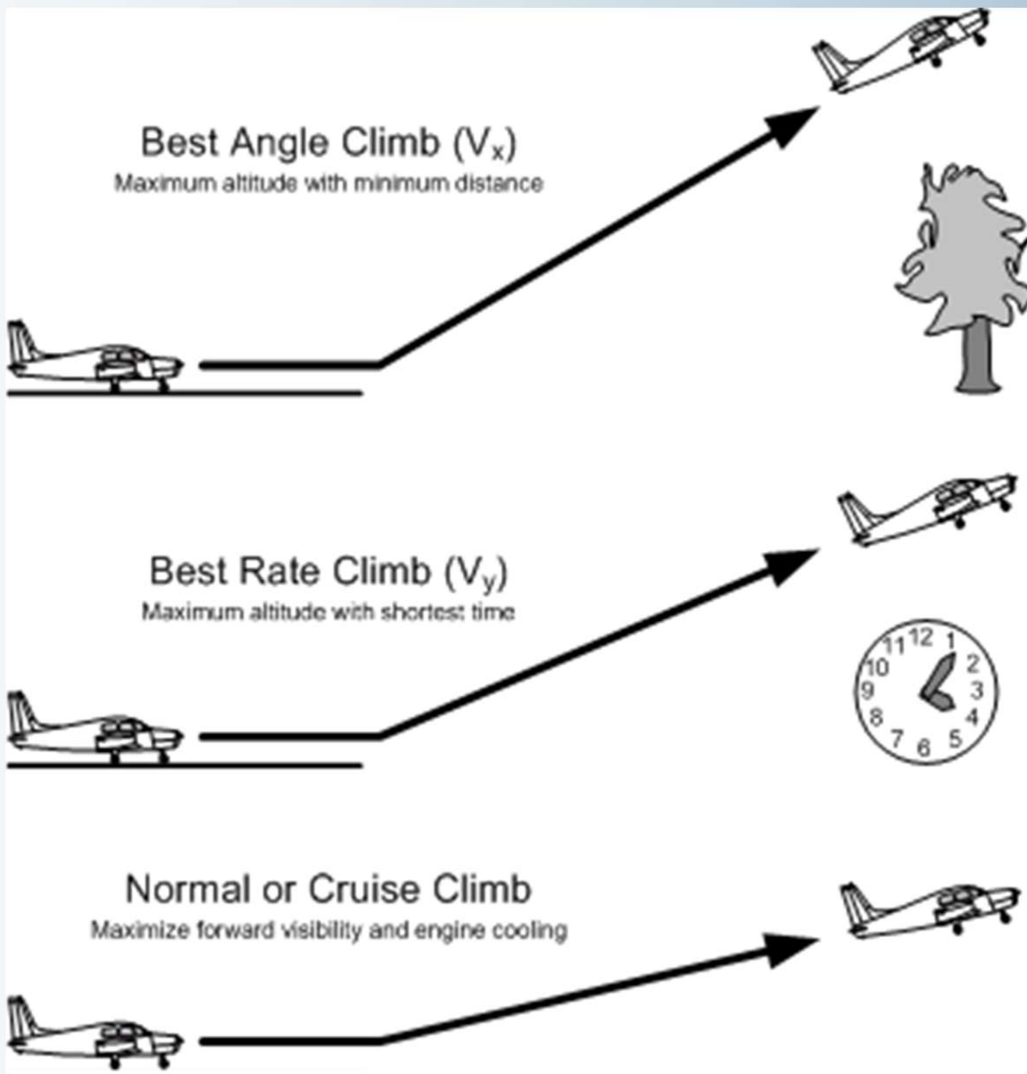
↓ minimum ground distance

↑ obstacle clearance

↓ visibility

↓ engine cooling

Types of Climbs



BRoC (V_Y)

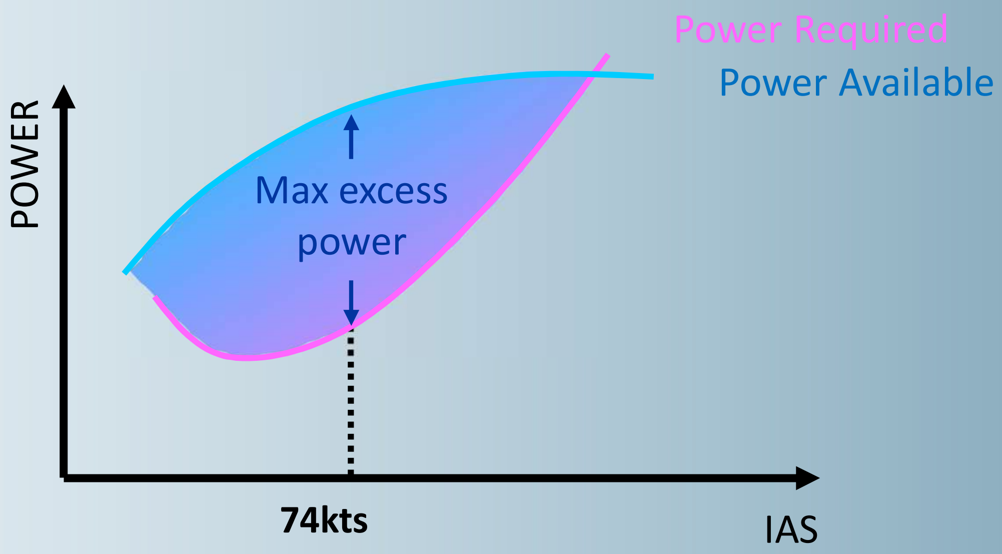
Power is a rate of doing work.

The work we are doing is climbing and the rate is the measure of time in which we climb.

Therefore, maximum excess power beyond what is required for S&L, will give BRoC.

BRoC (V_Y)(C172) = 74kts

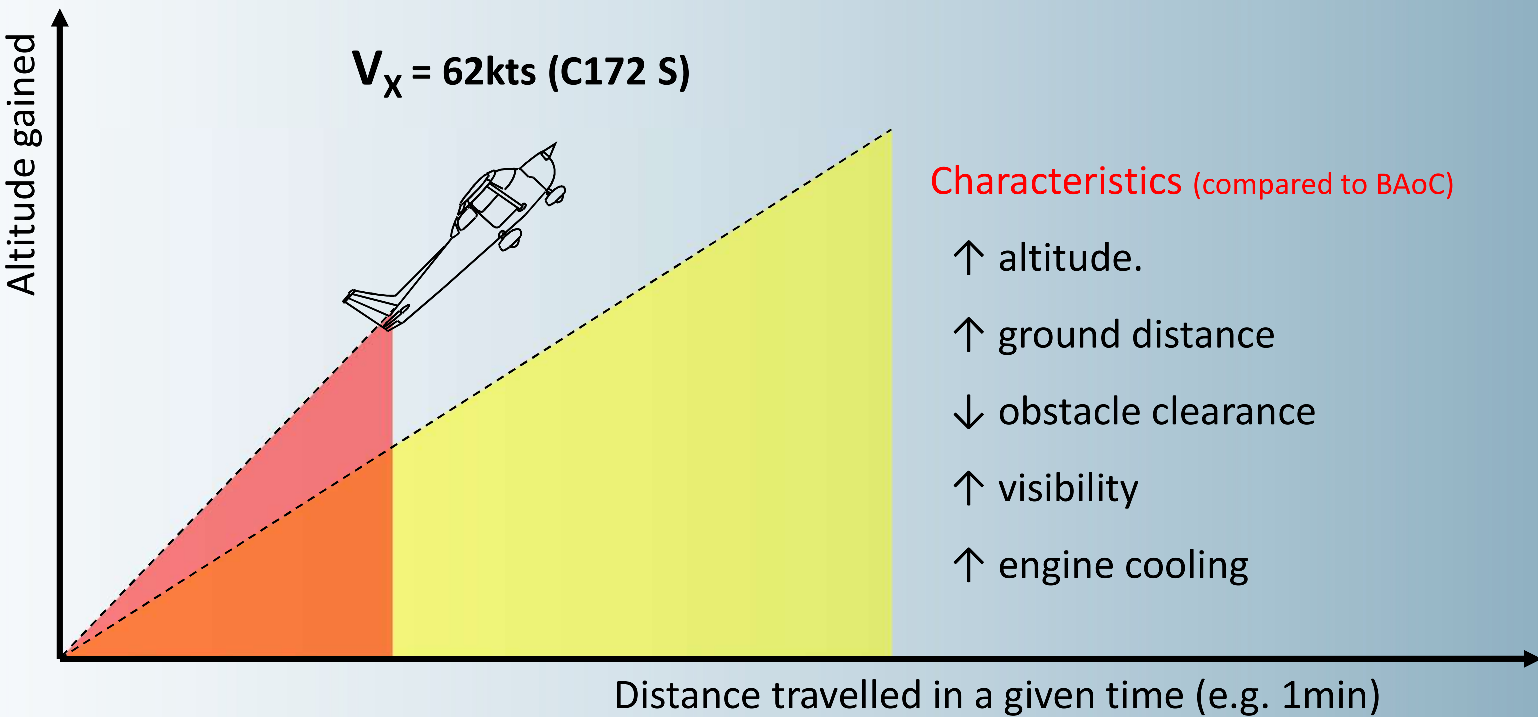
A decrease or increase in airspeed will decrease excess power available, decreasing the RoC.



BRoC (V_Y)

Best Rate of Climb (V_Y): $\frac{\text{Max altitude}}{\text{Given time}}$

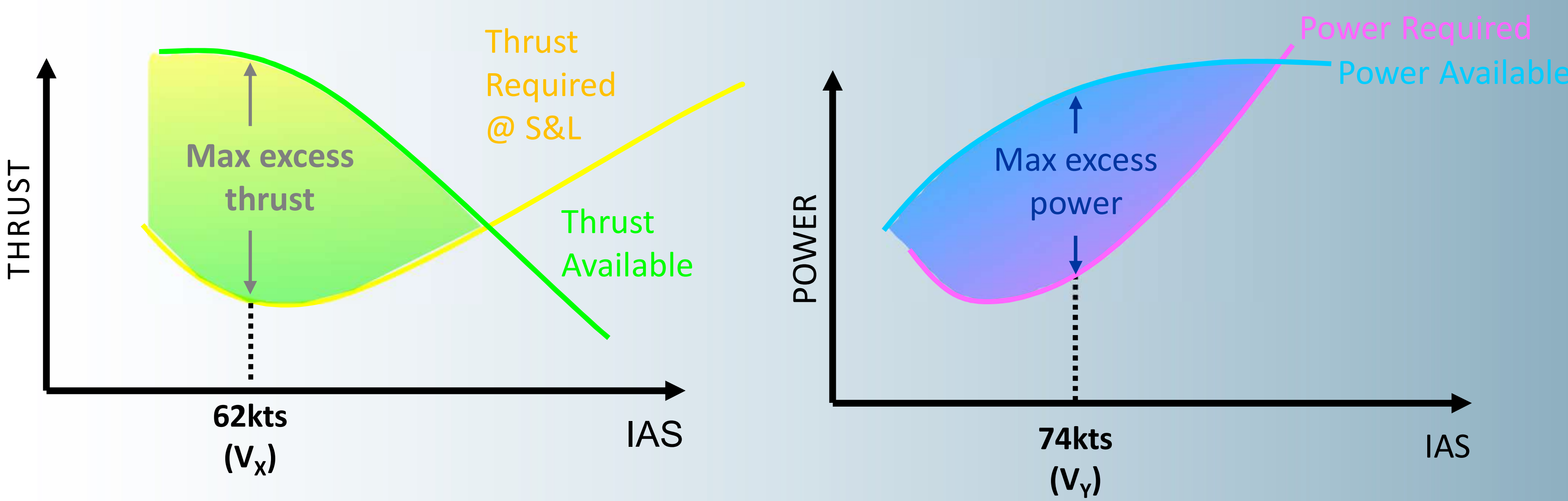
V_Y = 74kts (C172 S)



Characteristics (compared to BAoC)

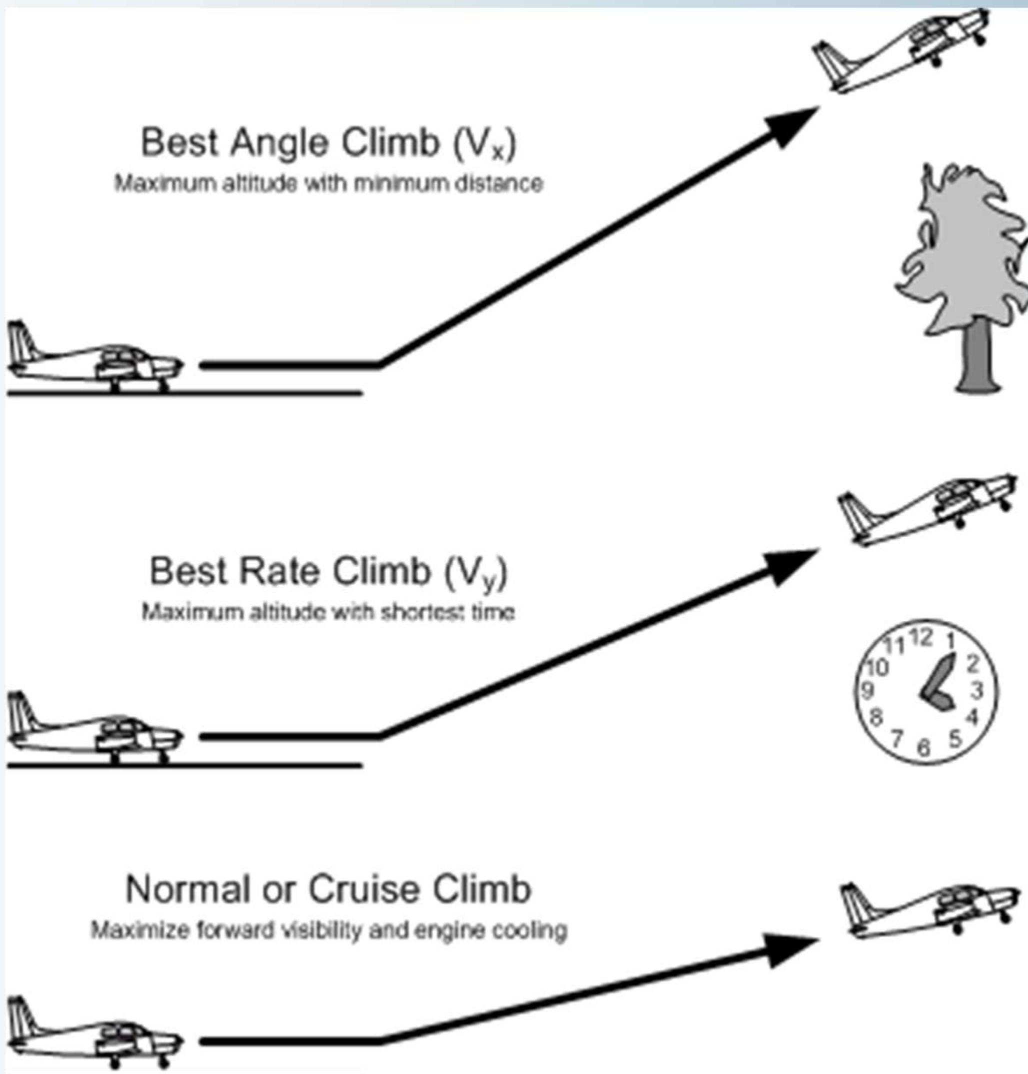
- ↑ altitude.
- ↑ ground distance
- ↓ obstacle clearance
- ↑ visibility
- ↑ engine cooling

BAoC/BRoC Summary



So BAoC occurs at Max Excess THRUST and BRoC occurs at Max Excess POWER

Types of Climbs

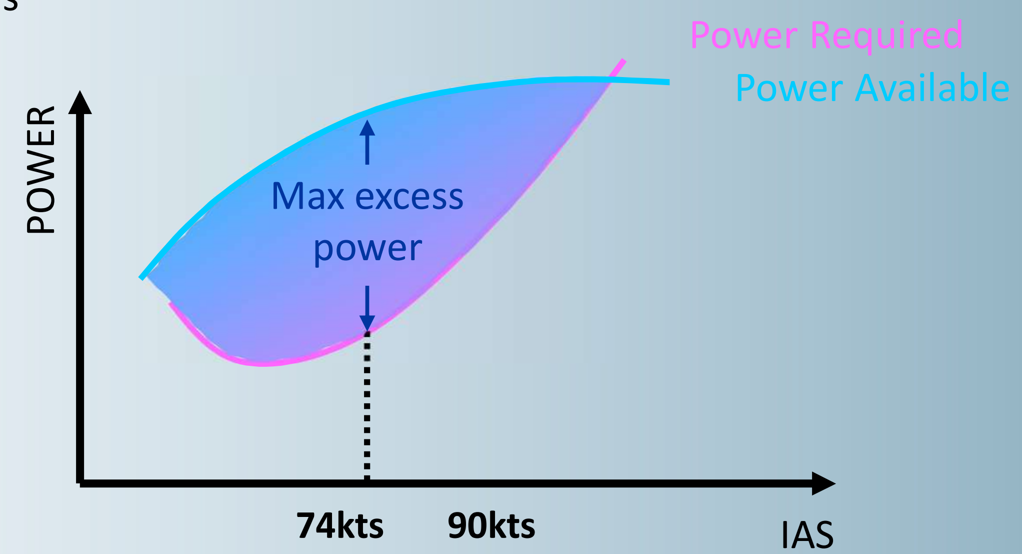


Cruise Climb (CRZ CLB)

Is a compromise between airspeed and rate of climb.

Used to maximise range when there is sufficient obstacle clearance

CRZ CLB (C172) = 90kts



Cruise Climb (CRZ CLB)

Cruise Climb: Trade altitude for increased ground distance.

Characteristics
(compared to other climb types)

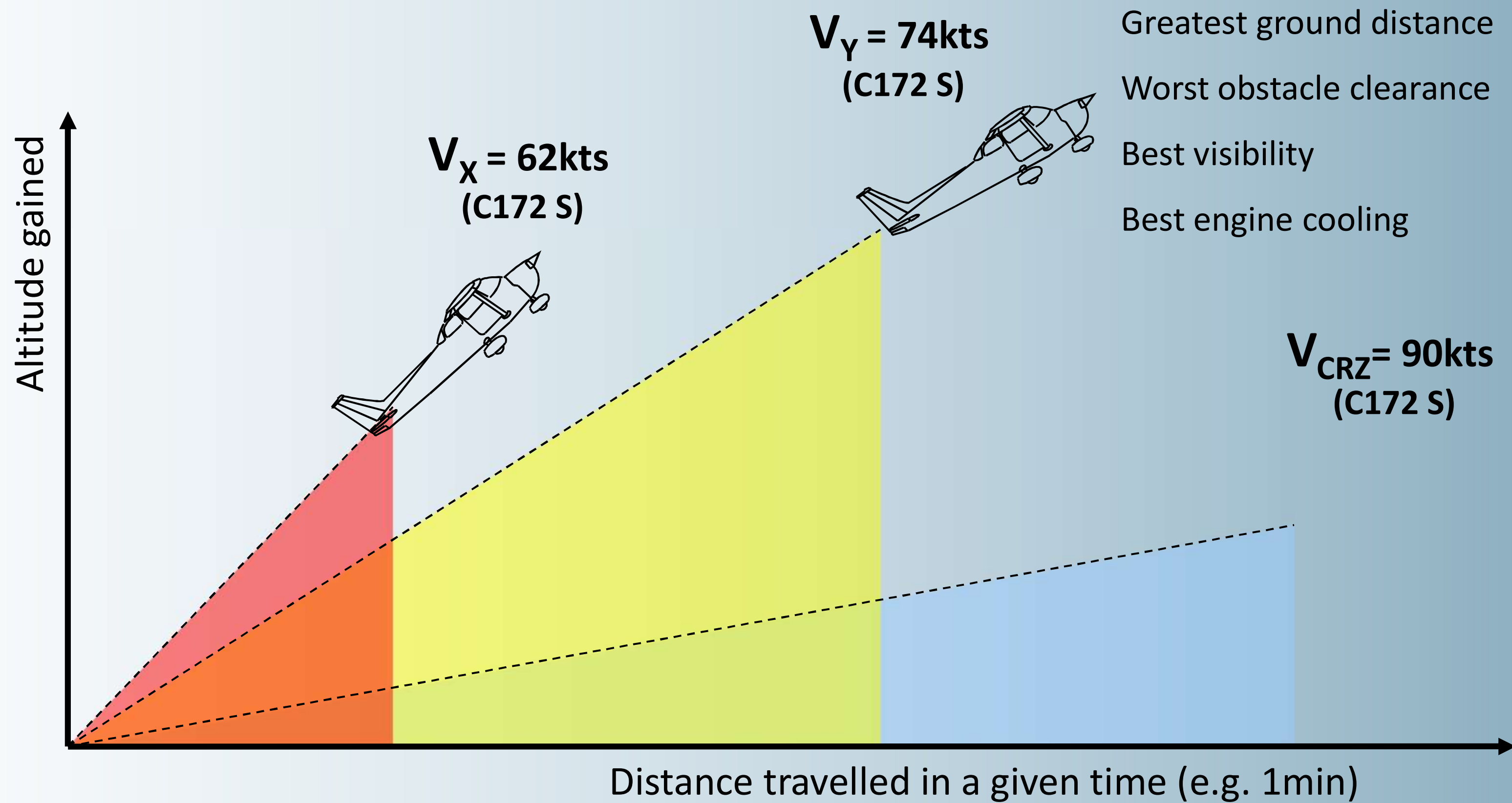
Best ground speed

Greatest ground distance

Worst obstacle clearance

Best visibility

Best engine cooling

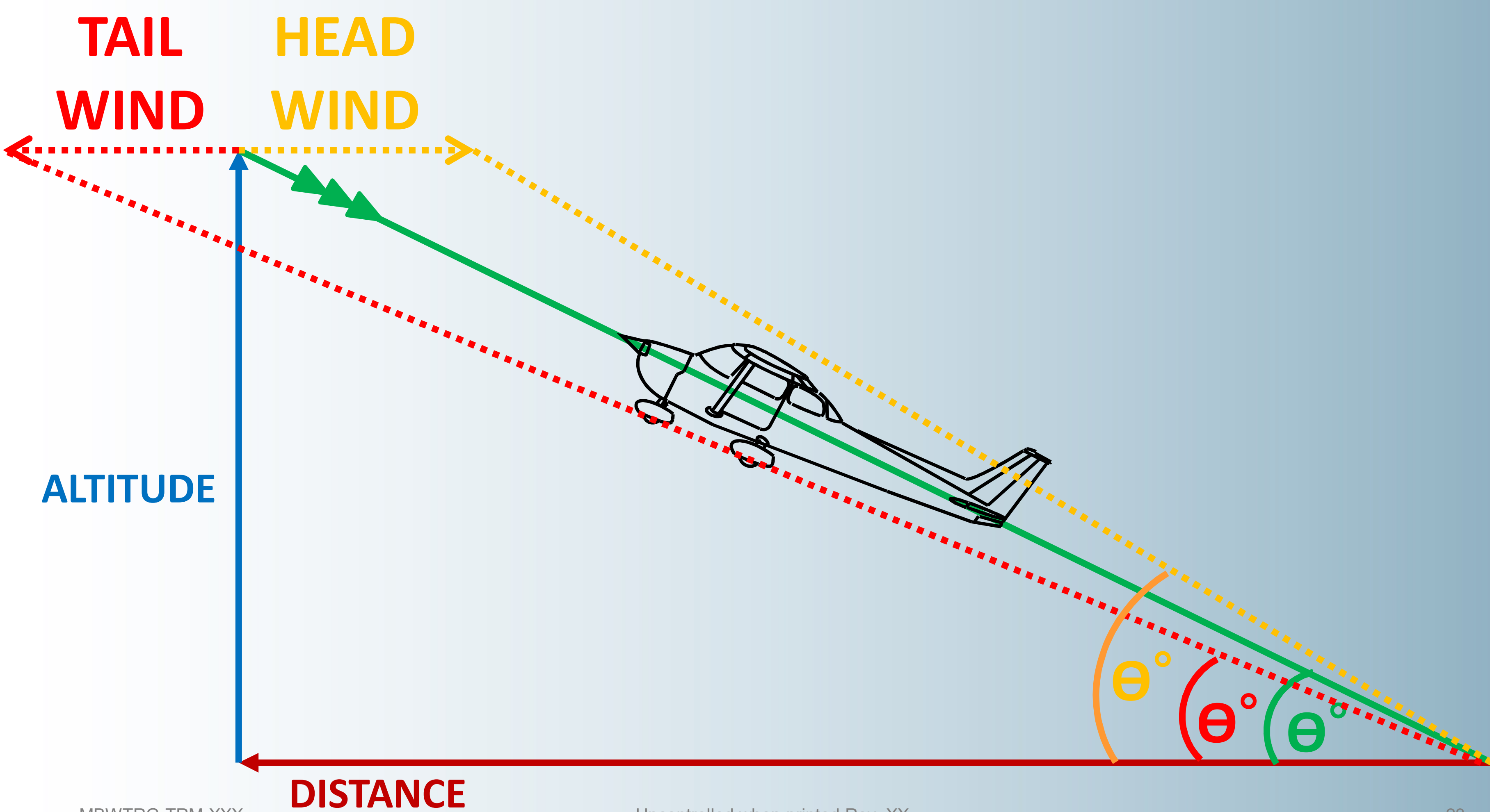


FACTORS AFFECTING CLIMB PERFORMANCE

CADA 5 – Climbing and Descending

	Angle of Climb	Rate of Climb
Headwind ↑		
Tailwind ↑		
Weight ↑		
Airspeed ↑↓		
Power ↓		
Flap ↘		
Altitude ↑		

Headwind/Tailwind



CADA 5 – Climbing and Descending

	Angle of Climb	Rate of Climb
Headwind ↑	↑	=
Tailwind ↑	↓	=
Weight ↑		
Airspeed ↑↓		
Power ↓		
Flap ↘		
Altitude ↑		

Weight

- A climb is an attempt to travel upwards
- An aircraft's weight due to gravity is acting against the climb
- Therefore, the greater the weight, the greater the downwards force acting against the climb
- **An increase in weight reduces climb performance**

Weight

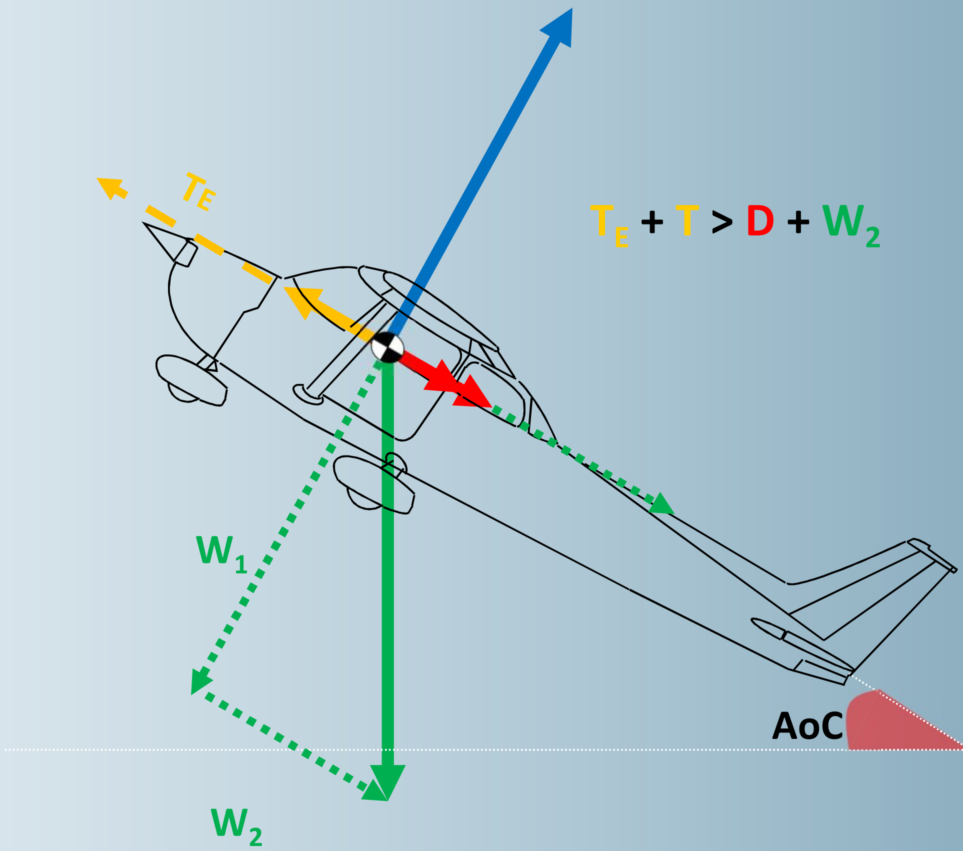
↓ Weight,

↓ W2 component acting in the direction of drag.

Lift required also ↓ hence ↓ Induced drag

The AoC needs to be increased to maintain a desired climb speed (BAoC 62 kts)

i.e. Pitch the nose up



WEIGHT INCREASE - OPPOSITE IS TRUE!

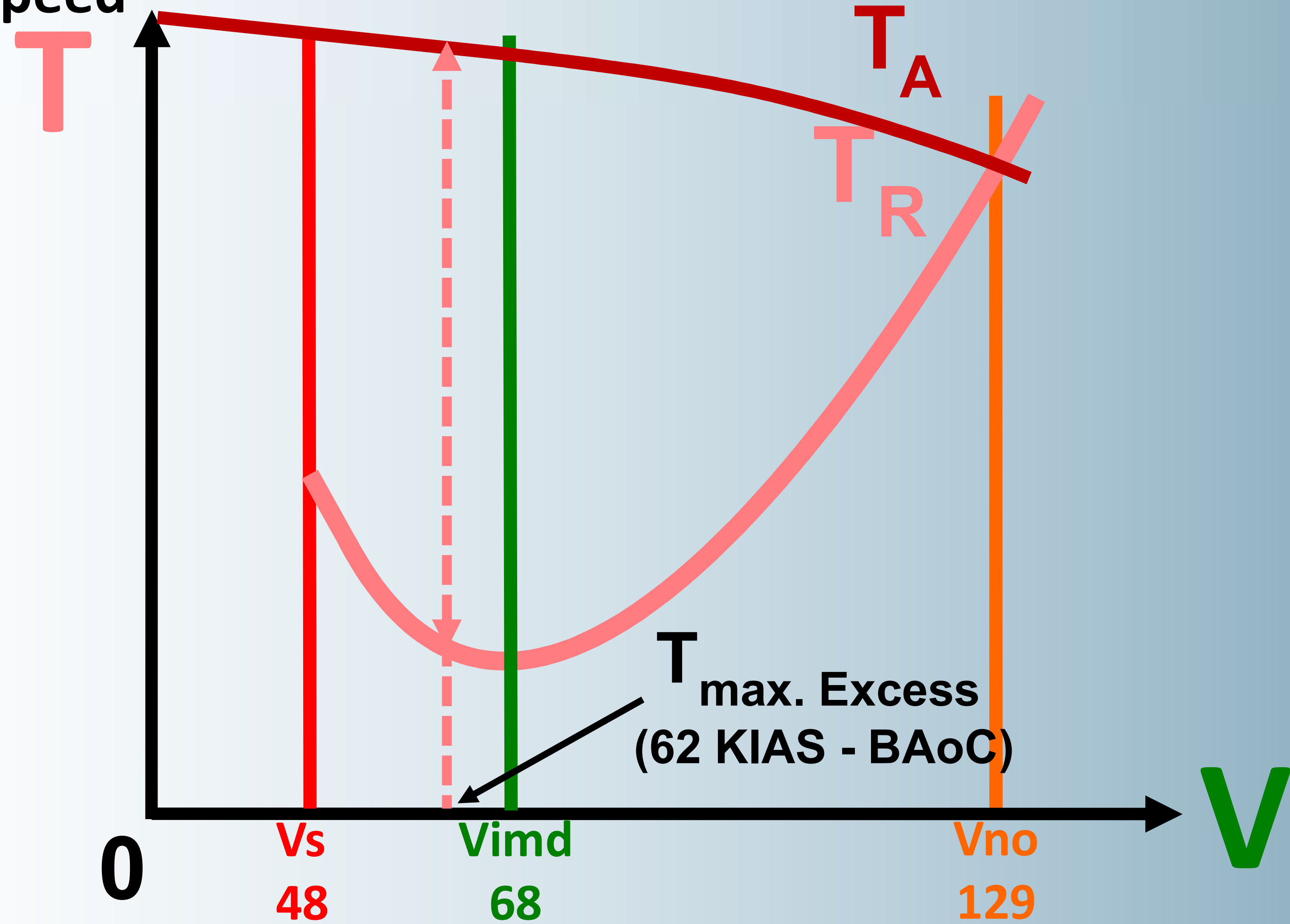
- LIFT
- THRUST
- WEIGHT
- DRAG

CADA 5 – Climbing and Descending

	Angle of Climb	Rate of Climb
Headwind ↑	↑	=
Tailwind ↑	↓	=
Weight ↑	↓	↓
Airspeed ↑↓		
Power ↓		
Flap ↘		
Altitude ↑		

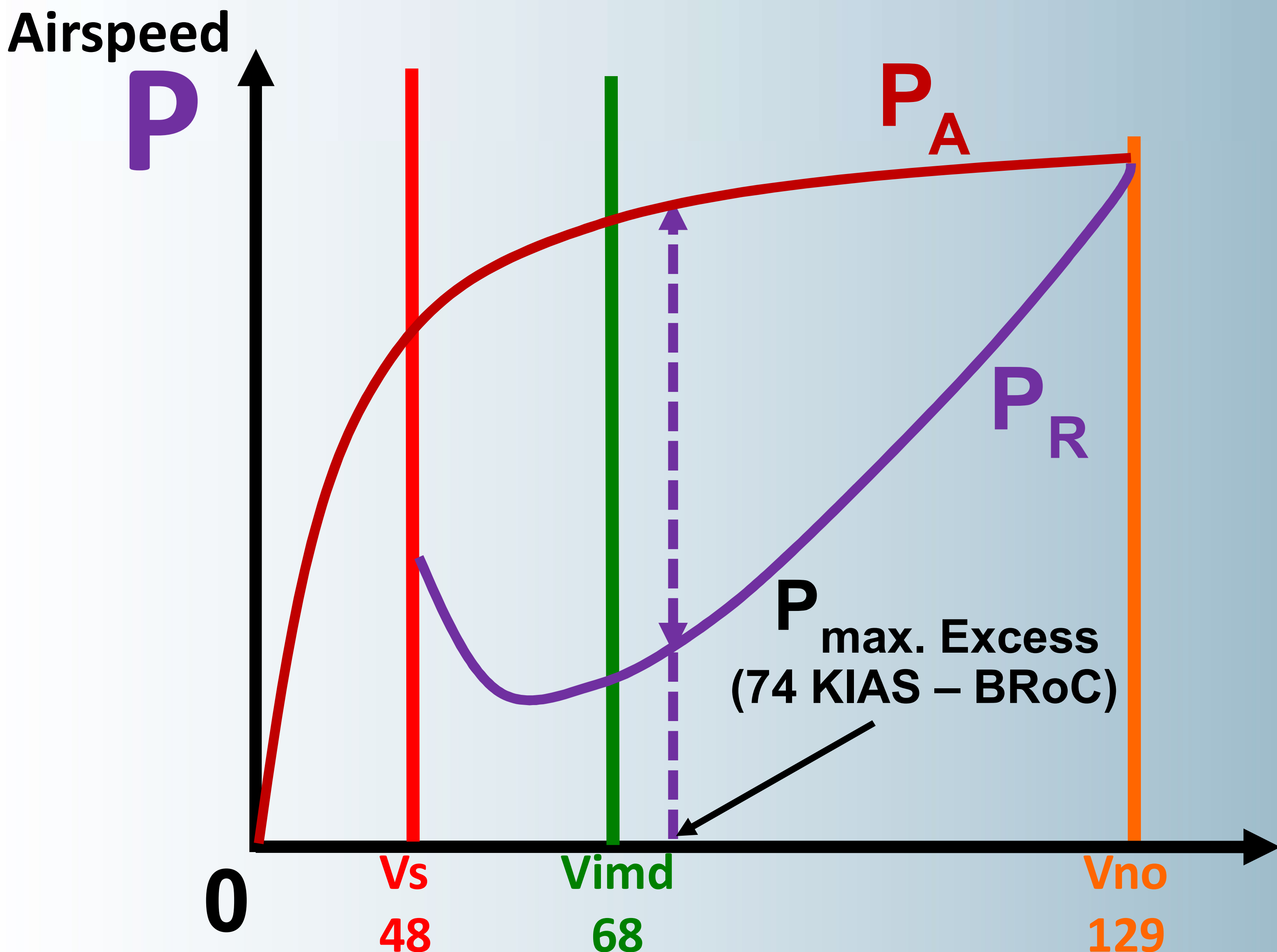
CADA 5 – Climbing and Descending

Airspeed



CADA 5 – Climbing and Descending

	Angle of Climb	Rate of Climb
Headwind ↑	↑	=
Tailwind ↑	↓	=
Weight ↑	↓	↓
Airspeed ↑↓	↓	
Power ↓		
Flap		
Altitude ↑		


Airspeed
P
P_A
P_R
$P_{max. Excess}$
(74 KIAS – BRoC)
0
Vs
48
Vimd
68
Vno
129

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CADA 5 – Climbing and Descending

	Angle of Climb	Rate of Climb
Headwind ↑	↑	=
Tailwind ↑	↓	=
Weight ↑	↓	↓
Airspeed ↑↓	↓	↓
Power ↓		
Flap ↘		
Altitude ↑		

Power

- If we reduce the power, the result will be:

1. Less power available

2. Less thrust available

- This means that **both Angle and Rate of Climb will be reduced**
- This is why we usually climb at full power

CADA 5 – Climbing and Descending

	Angle of Climb	Rate of Climb
Headwind ↑	↑	=
Tailwind ↑	↓	=
Weight ↑	↓	↓
Airspeed ↑↓	↓	↓
Power ↓	↓	↓
Flap ↘		
Altitude ↑		

Flap

- Flaps increase both:

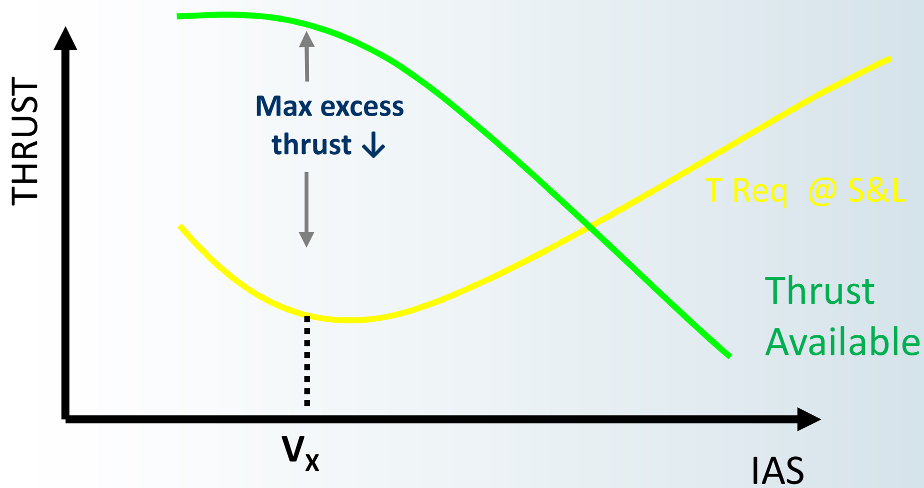
1. Lift

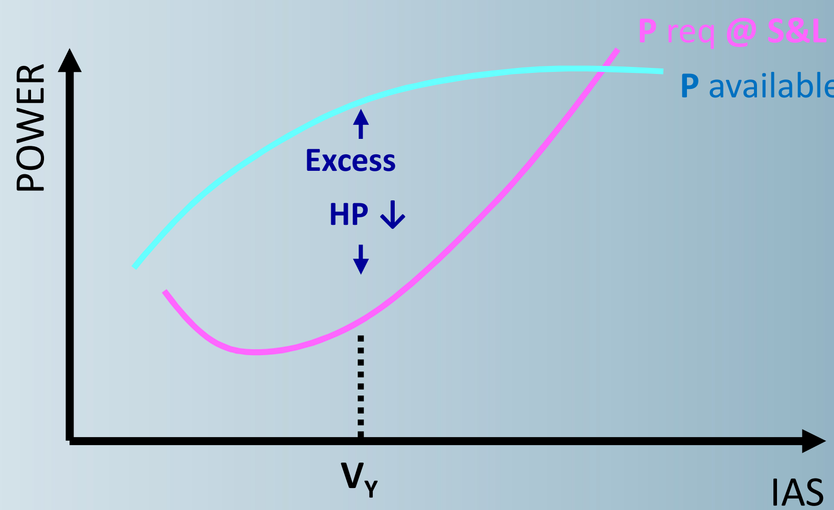
2. Drag

- The increase in drag reduces the amount of excess thrust available
- **Flaps reduce both the Angle and Rate of Climb**
- Despite this, we use flaps on take-off sometimes as the increase in lift allows us to become airborne sooner i.e. reduces the ground roll

Flap

- Large settings ↑ drag,
- which ↑ both power & thrust required,
- ↓ climb performance.





CADA 5 – Climbing and Descending

	Angle of Climb	Rate of Climb
Headwind ↑	↑	=
Tailwind ↑	↓	=
Weight ↑	↓	↓
Airspeed ↑↓	↓	↓
Power ↓	↓	↓
Flap ↘	↓	↓
Altitude ↑		

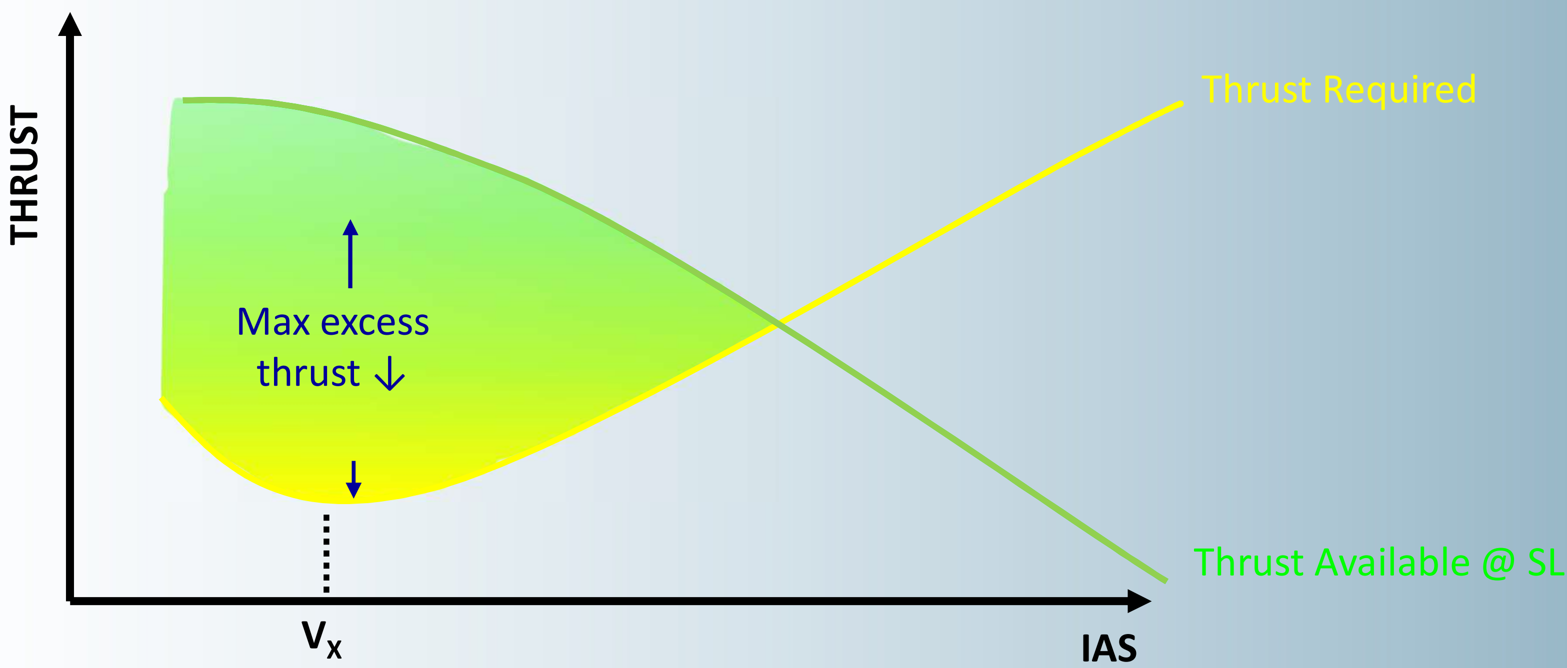
Altitude

- As altitude increases, the air becomes less dense
- This means the engine will not be able to produce as much power
- It also means the propeller will not be able to generate as much thrust
- **An increase in altitude reduces both the Angle and Rate of Climb**

Altitude

Due to ↓ air density, ↓ amount of air available for combustion, engine power ↓.

- Thrust Available at altitude ↓



Regardless of altitude, Vx remains the same however there is a reduced climb performance at altitude

Altitude

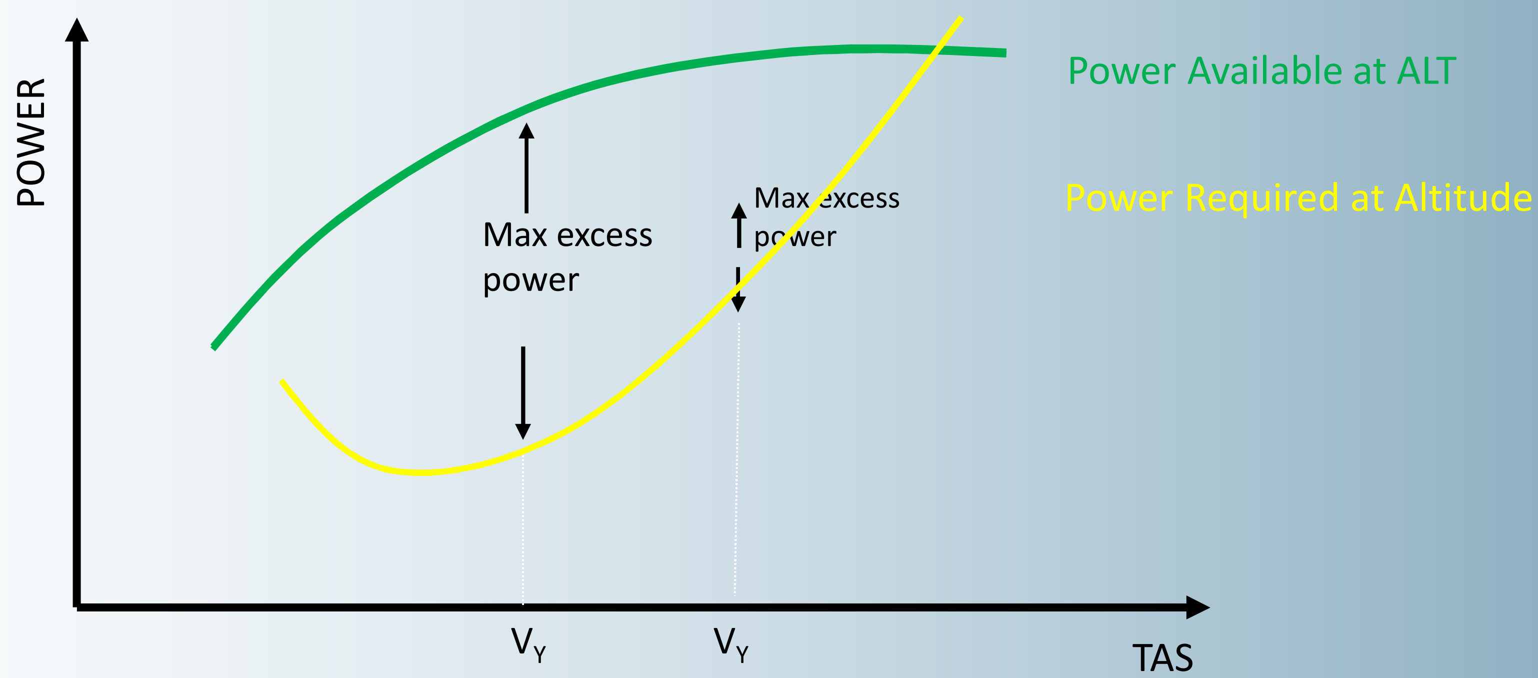
With an increase Altitude,

Therefore: power available ↓ ,
power required ↑

↓ Max excess power, ↓ climb performance.

$L = C_L \frac{1}{2} \rho V^2 S$

↓ ↑



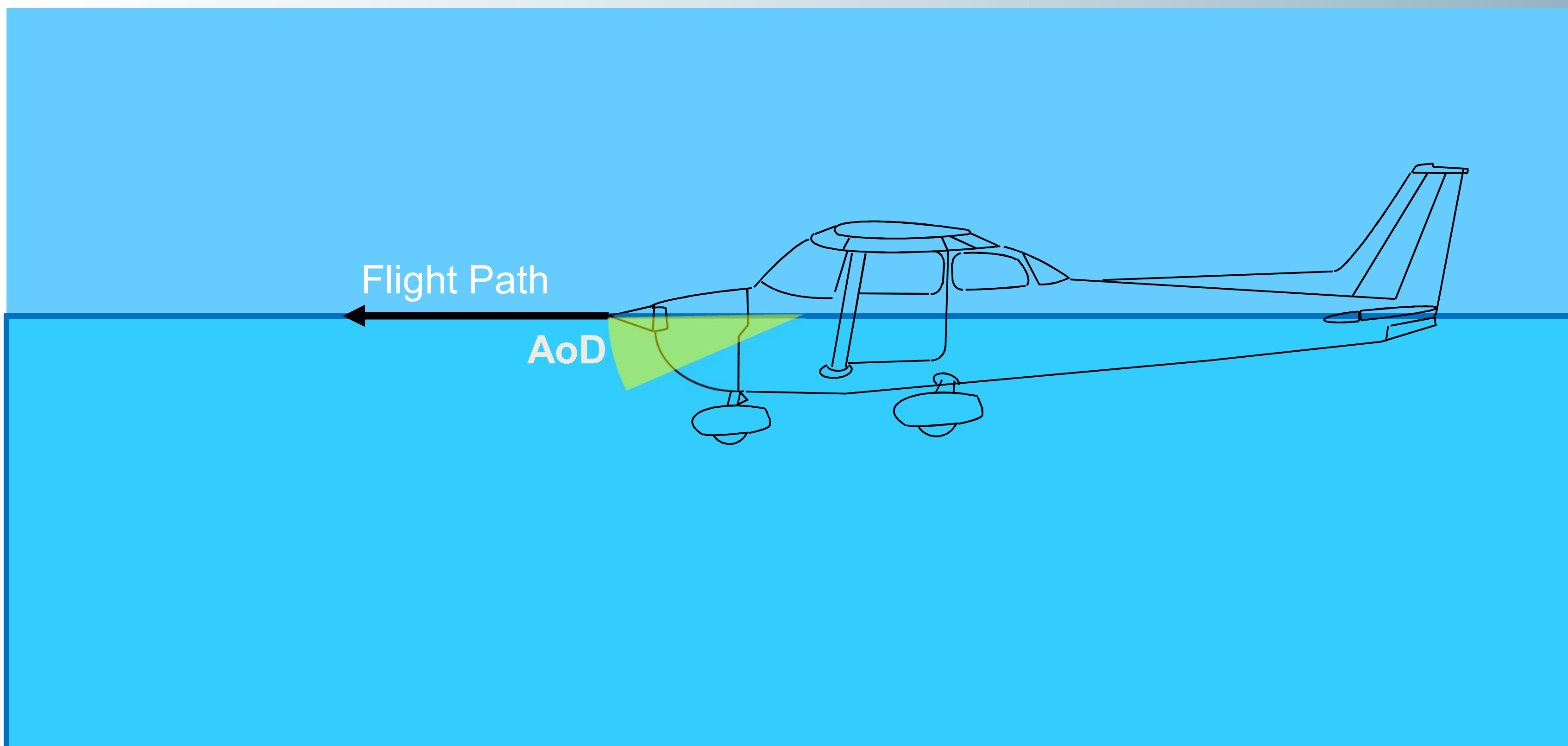
CADA 5 – Climbing and Descending

	Angle of Climb	Rate of Climb
Headwind ↑	↑	=
Tailwind ↑	↓	=
Weight ↑	↓	↓
Airspeed ↑↓	↓	↓
Power ↓	↓	↓
Flap ↘	↓	↓
Altitude ↑	↓	↓

DESCENDING

Angle of Descent

Angle between the flight path and the horizon.



FORCES IN A STEADY DESCENT

Forces in a Steady Descent

Normal S+L flight condition

Drag has no opposite force of equal magnitude.

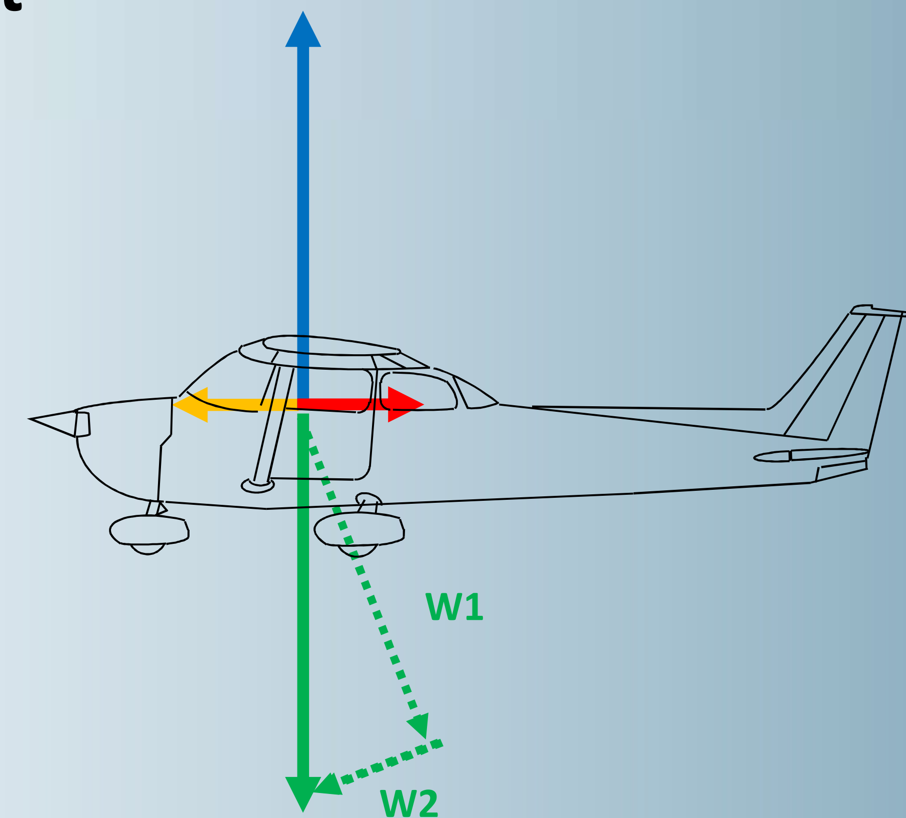
Aircraft is not in equilibrium!

If you maintain S+L flight, the aircraft would lose airspeed.

Course Of Action:

Fly at the AoA for best L/D Ratio (68 kts) and **MAINTAIN** it.

To maintain the 68Kts, an "apparent" thrust force is required to restore equilibrium.

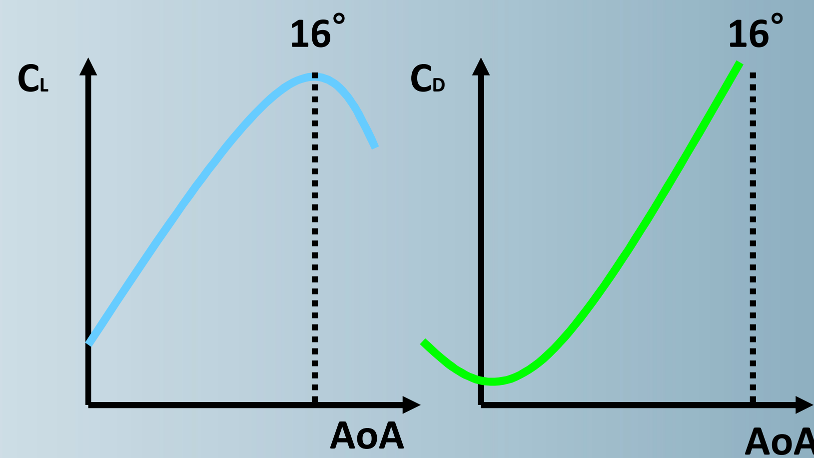


By lowering the nose and accepting an Angle of Descent, equilibrium restored!

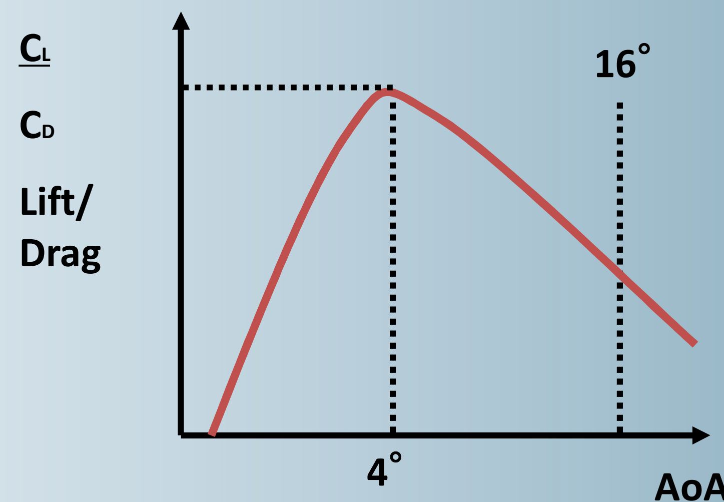
LIFT/DRAG RATIO

Lift/Drag Ratio

Gliding distance depends on L:D ratio = $\frac{C_L}{C_D}$ for a given AoA



As the AoA increases, C_L steadily increases up to 16° AoA, while C_D increases exponentially after a low AoA.



Best L:D ratio is at an AoA of about 4°, this is the most efficient AoA for this aerofoil.

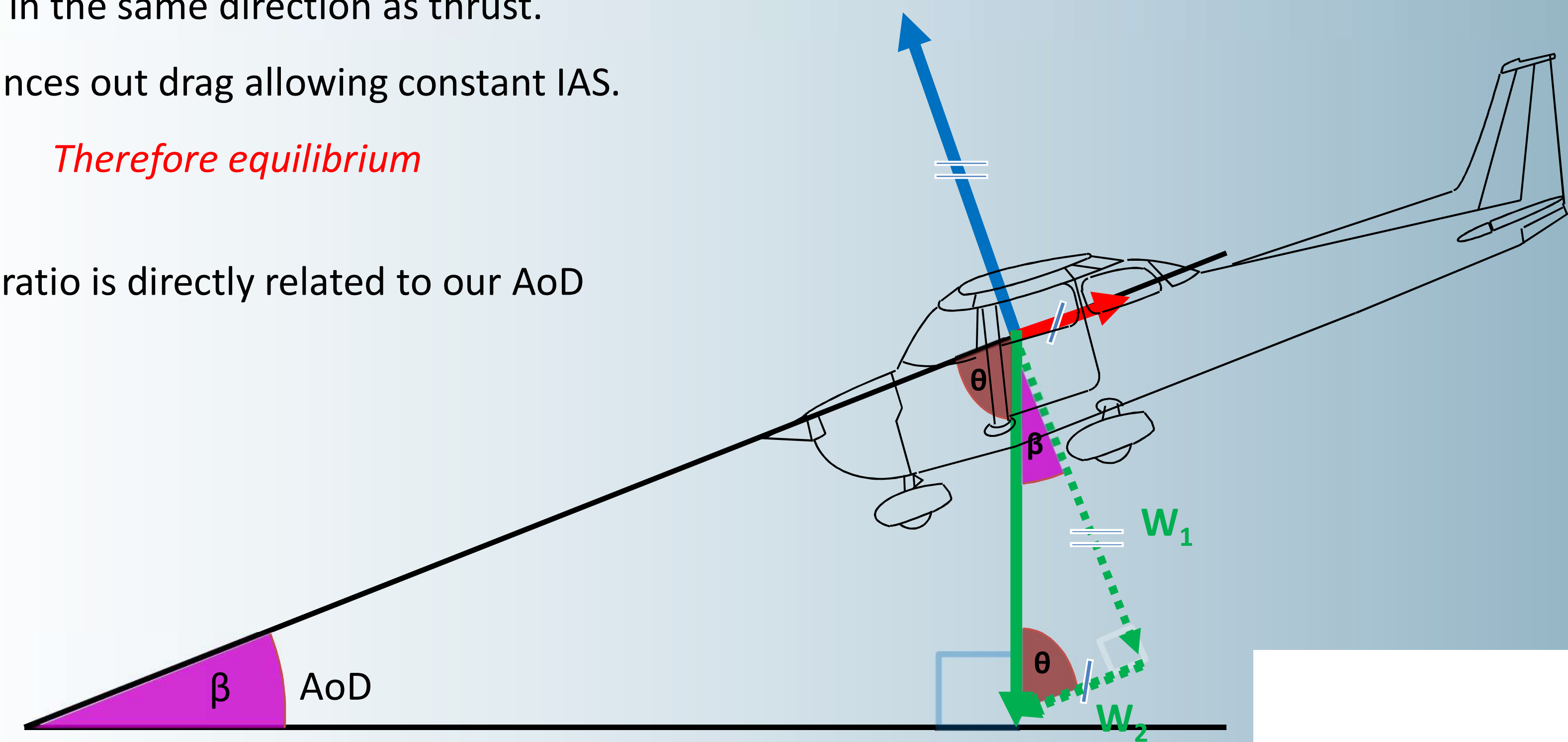
Lift/Drag Ratio

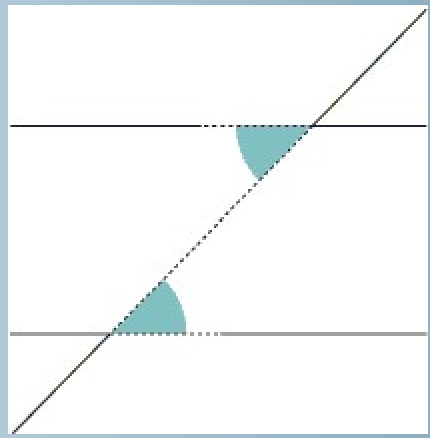
W2 acts in the same direction as thrust.

W2 balances out drag allowing constant IAS.

Therefore equilibrium

Our L:D ratio is directly related to our AoD





FACTORS AFFECTING DESCENT PERFORMANCE

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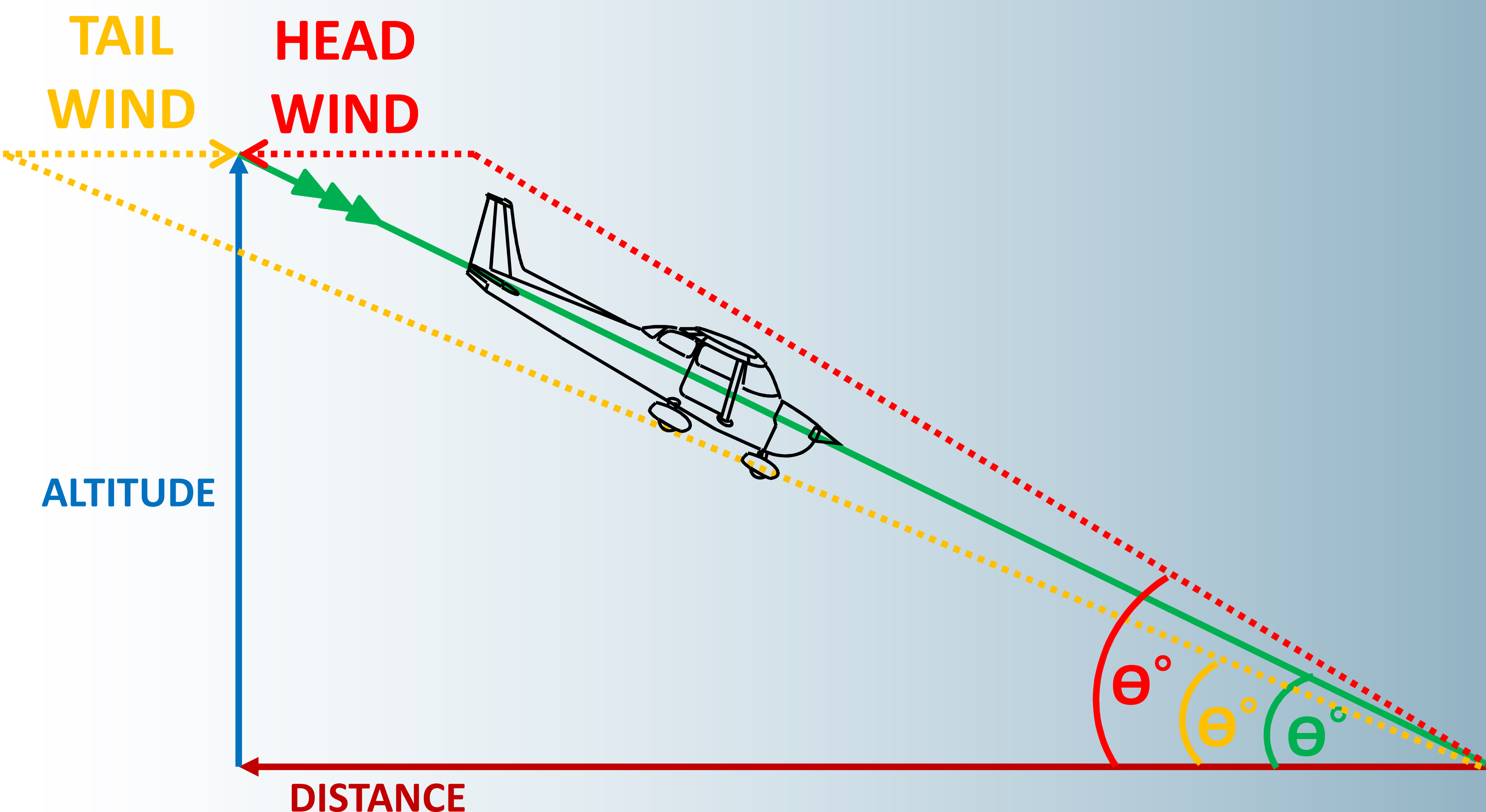
CADA 5 – Climbing and Descending

	Angle of Descent	Rate of Descent
Headwind ↑		
Tailwind ↑		
Weight ↑		
Airspeed ↑↓		
Power ↑		
Flap ↘		

Headwind/Tailwind



Headwind/Tailwind

Headwind

RoD unchanged

↓ Ground distance

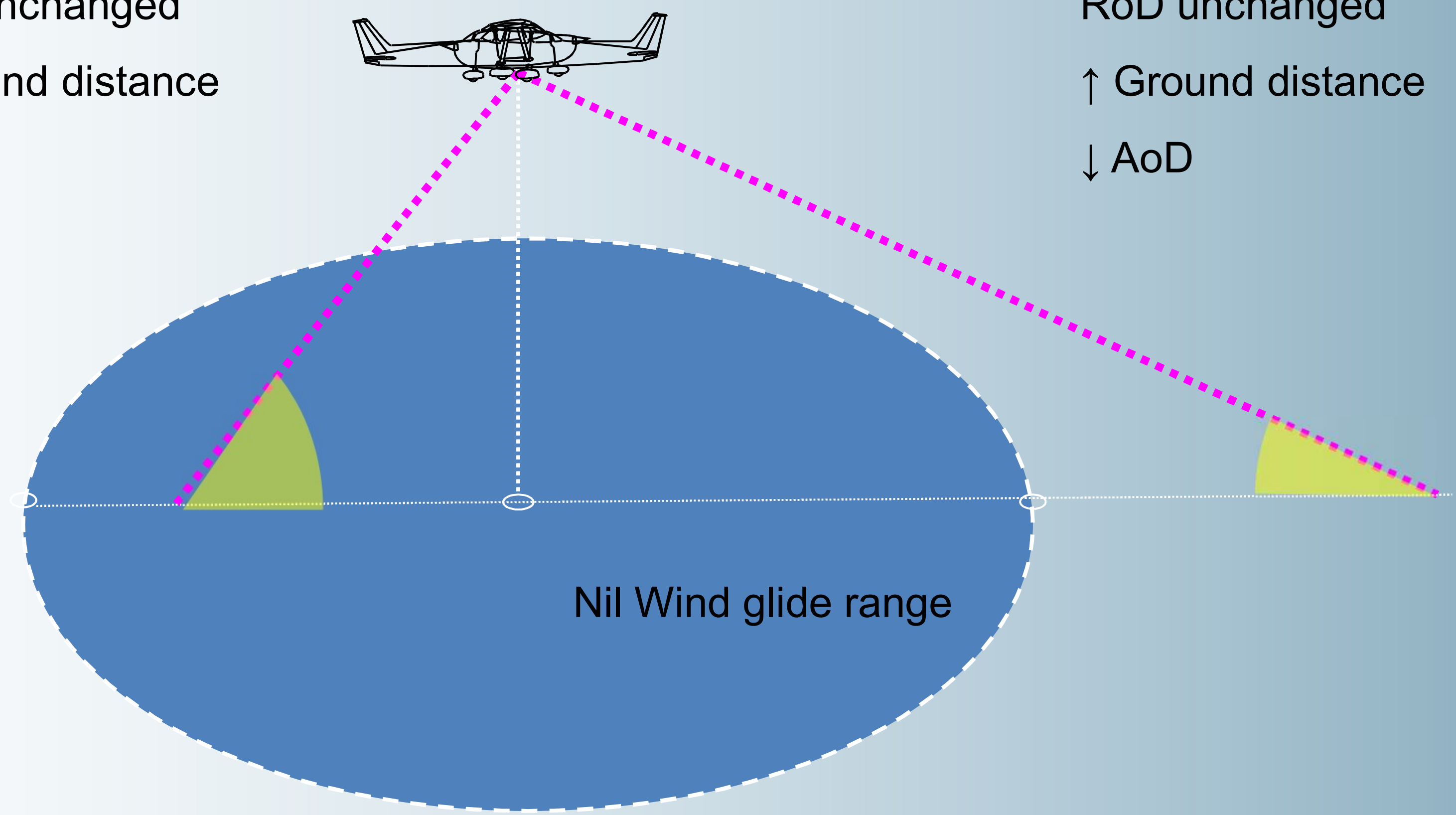
↑ AoD

Tailwind

RoD unchanged

↑ Ground distance

↓ AoD



Note: Headwind requires increased speed for range if necessary

The rule of thumb to use is: *add 25% of the headwind to your speed*

CADA 5 – Climbing and Descending

	Angle of Descent	Rate of Descent
Headwind ↑	↑	=
Tailwind ↑	↓	=
Weight ↑		
Airspeed ↑↓		
Power ↑		
Flap ↘		

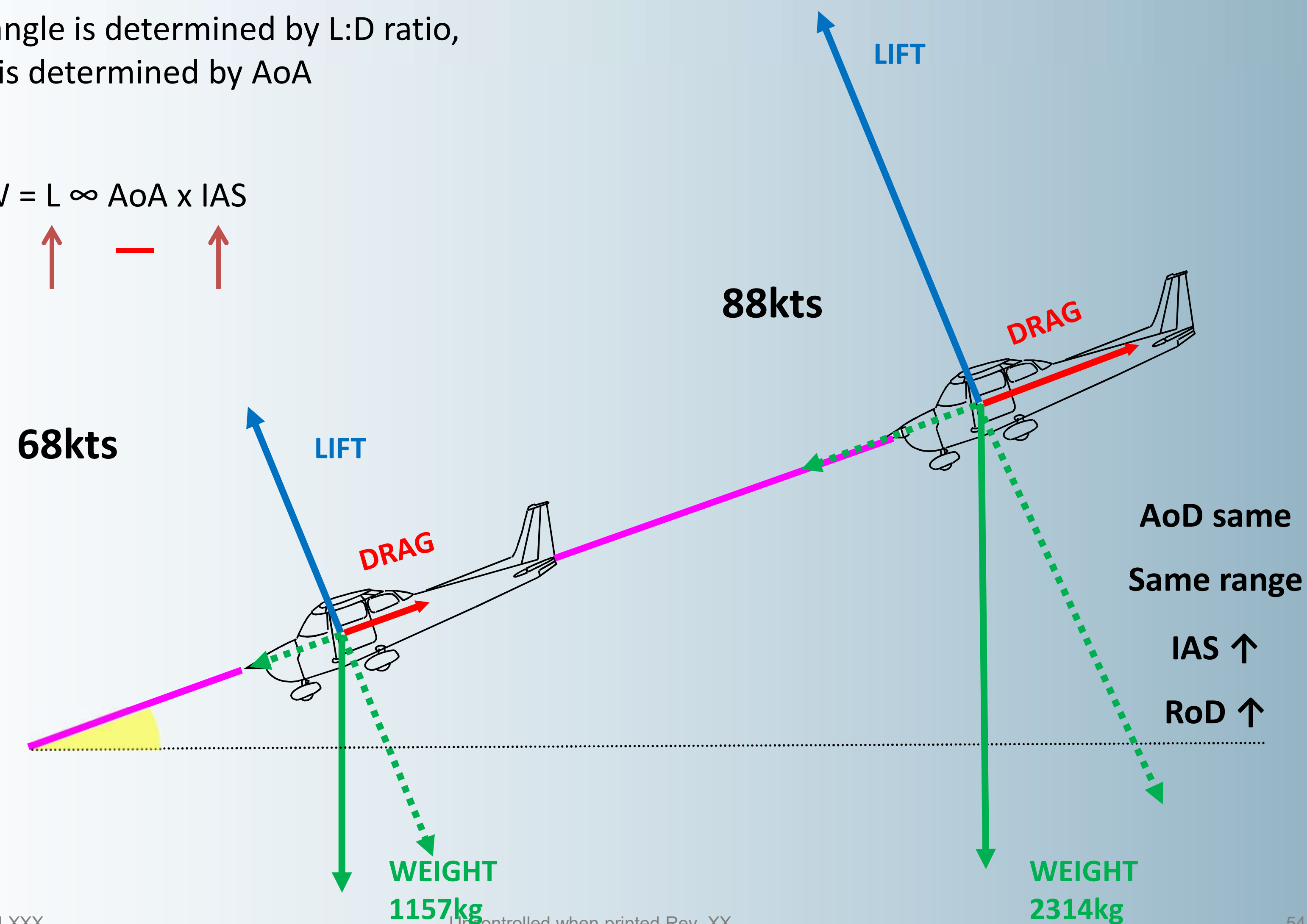
Weight

- The glide range is dependent upon the L/D Ratio
- Weight is not a factor! **Therefore, glide range (and angle) will not change!**
- However, weight affects the rate of descent as there is a component of weight acting along the flight path
- **Weight increases the rate of descent**

Weight

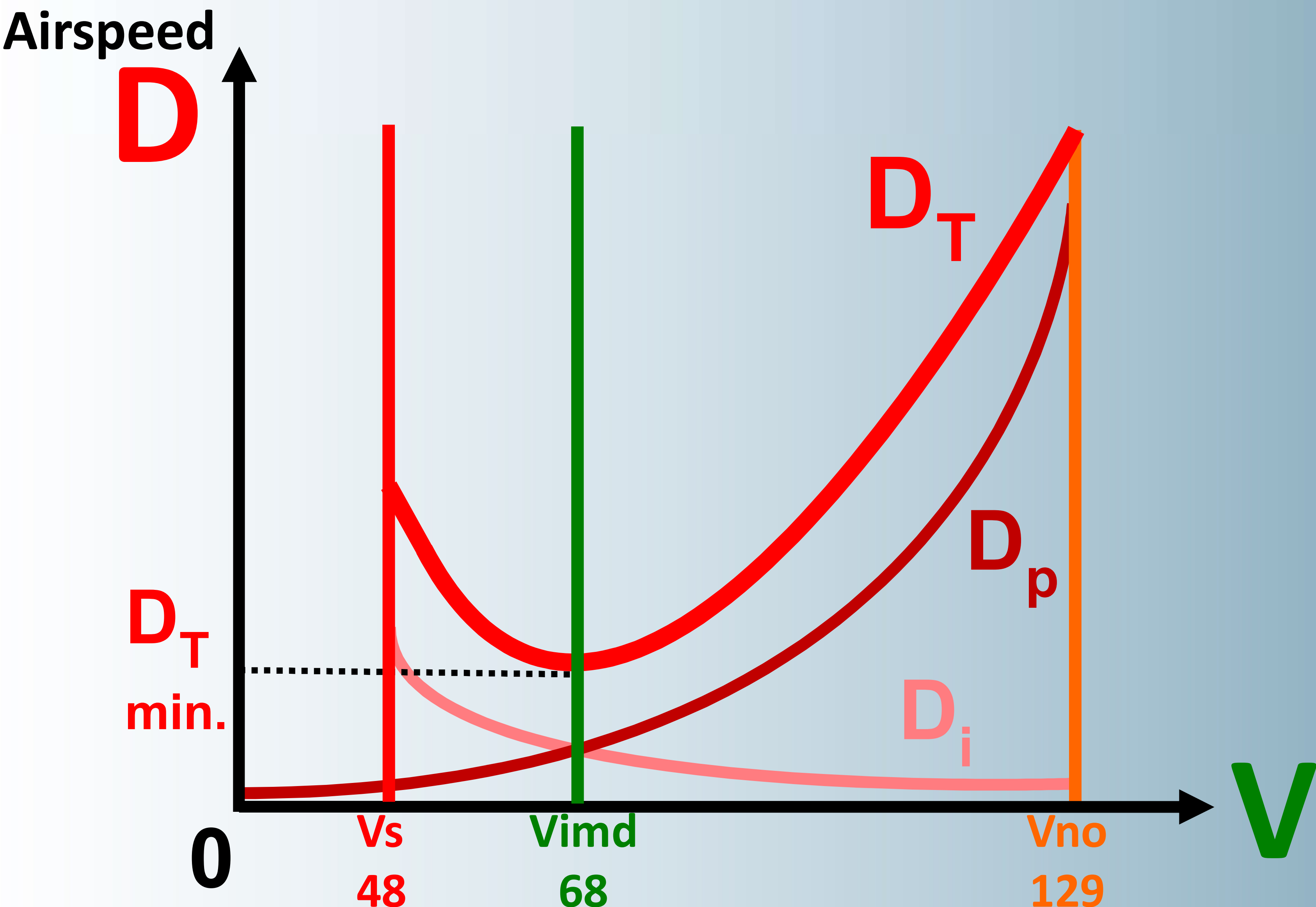
Glide angle is determined by L:D ratio, which is determined by AoA

W = L ∞ AoA x IAS



CADA 5 – Climbing and Descending

	Angle of Descent	Rate of Descent
Headwind ↑	↑	=
Tailwind ↑	↓	=
Weight ↑	=	↑
Airspeed ↑↓		
Power ↑		
Flap		



Airspeed
D
D_T
D_p
D_i
D_T
min.
0
Vs
48
Vimd
68
Vno
129
V

CADA 5 – Climbing and Descending

	Angle of Descent	Rate of Descent
Headwind ↑	↑	=
Tailwind ↑	↓	=
Weight ↑	=	↑
Airspeed ↑↓	↑	↑
Power ↑		
Flap ↘		

Power

- If the power is increased, the only way to maintain a constant descent speed is to raise the nose
- **This will reduce the Angle of Descent**
- With a constant descent speed and a now higher nose attitude, **the Rate of Descent will also be reduced**

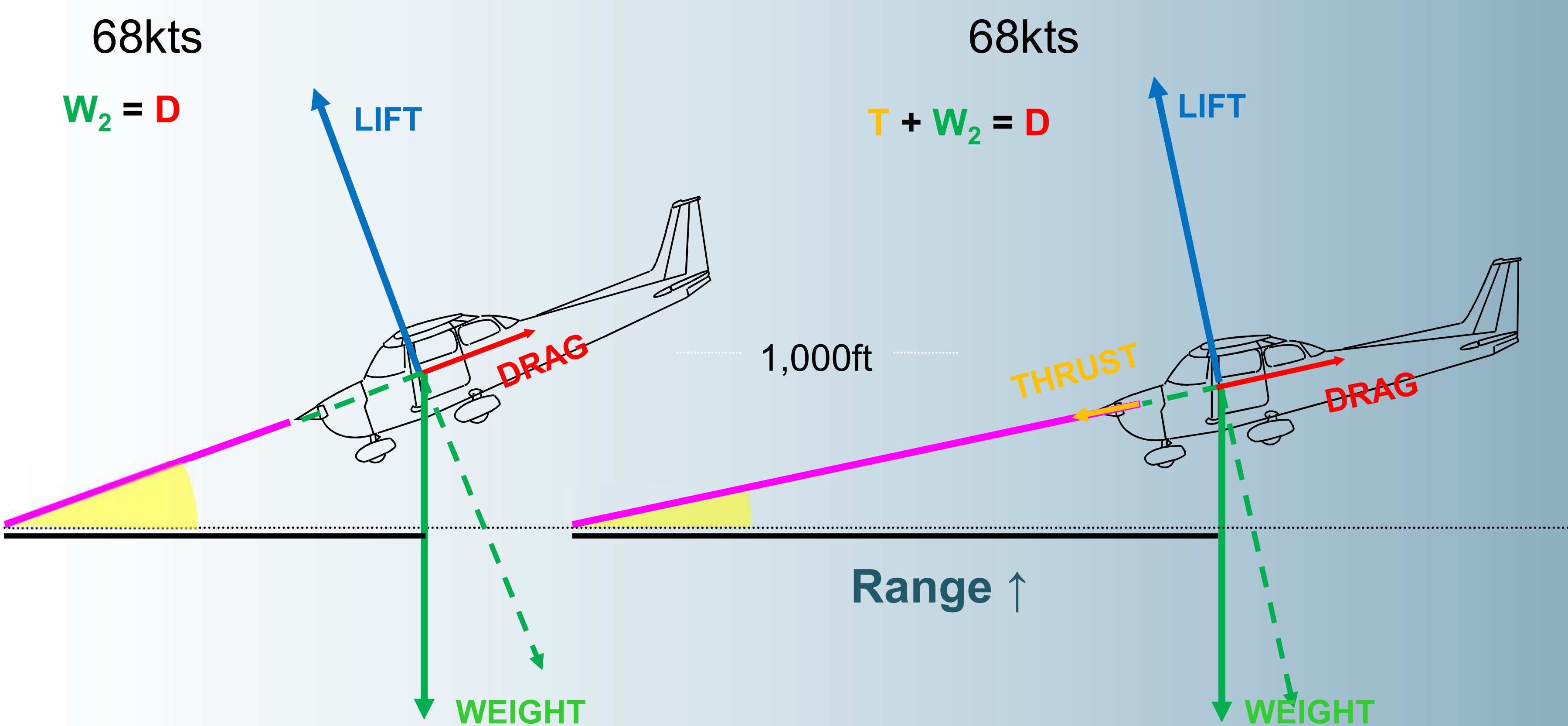
Remember:

"Power flattens the descent"

Power

With the application of thrust a ↓ component of W_2 is required down the flight path.

AoD is ↓ , RoD is ↓ and Range ↑



CADA 5 – Climbing and Descending

	Angle of Descent	Rate of Descent
Headwind ↑	↑	=
Tailwind ↑	↓	=
Weight ↑	=	↑
Airspeed ↑↓	↑	↑
Power ↑	↓	↓
Flap ↘		

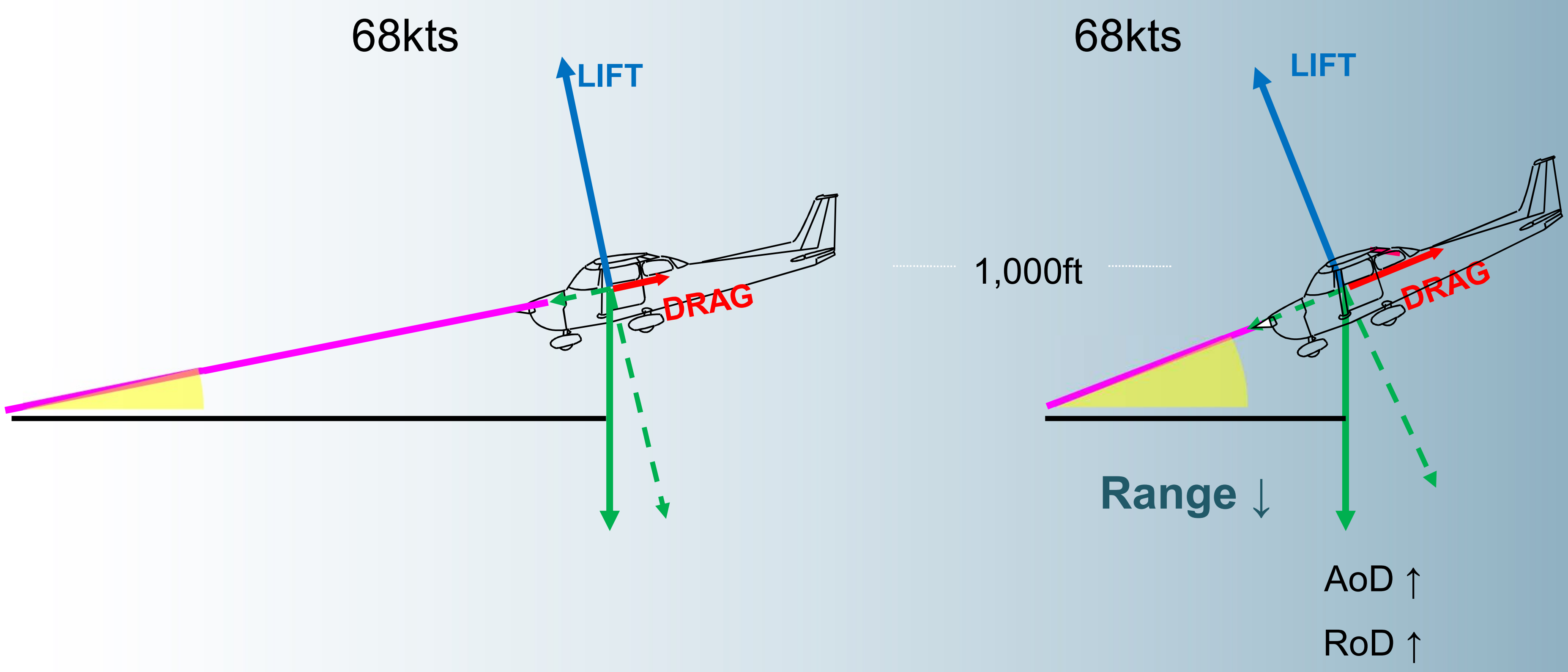
Flap

- Flaps increase drag. Therefore, to maintain a constant descent speed, the nose must be lowered
- **This means the Angle of Descent increases**
- If we have the same descent speed but now an increased Angle of Descent, **the Rate of Descent will also increase**

Flap

Greater ↑ drag proportionally to lift (high settings). Therefore L:D ↓

To maintain constant speed, lower the nose:



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CADA 5 – Climbing and Descending

	Angle of Descent	Rate of Descent
Headwind ↑	↑	=
Tailwind ↑	↓	=
Weight ↑	=	↑
Airspeed ↑↓	↑	↑
Power ↑	↓	↓
Flap ↘	↑	↑

WINDSHEAR

Windshear

- Windshear**:** a sudden change in *wind speed* and or/direction

What happens if we encounter windshear on climb/descent?

Increase in headwind = sudden **increase** in IAS and lift

Decrease in headwind = sudden **decrease** in IAS and lift

Decrease in tailwind = sudden **increase** in IAS and lift

GROUND EFFECT

Ground Effect

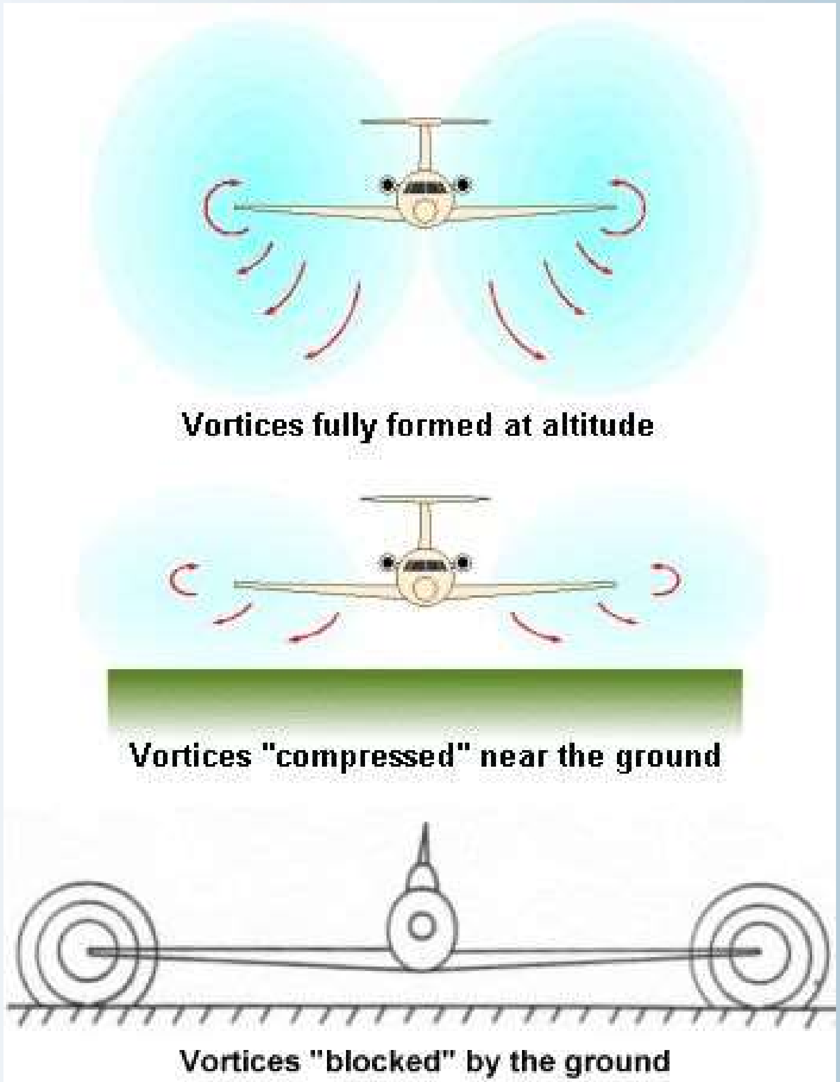
- The flight characteristics of an aircraft change when it gets close to the ground or any other surface
  - It can fly at a slower speed than when it is at altitude (V_S ↓)
  - It can fly at the same speed using less thrust than when it is at altitude

- This is a result of a cushioning effect caused by the air between the wing and the ground. This is known as Ground Effect

Ground Effect

- Ground effect becomes noticeable when <u>within one wingspan</u> of the ground, and the effect becomes greater the closer the wing is to the surface
- When flying close to the ground, the surface interferes with the airflow around the wings. This restricts upwash and downwash, and the formation of wingtip vortices
- When in ground effect an aerofoil will create a greater amount of lift at the same angle of attack, and a reduction in induced drag
- Ground effect is most significant during take-off and landing

Ground Effect



Ground Effect During Landing

- As a result of extra lift and reduction in drag, the pilot will experience a floating sensation

- The increased float distance is undesirable, especially when landing on strips of marginal length

Ground Effect During Take-Off

- As the aircraft climbs out of ground effect, the lift coefficient will decrease for the same aircraft pitch attitude. Induced drag will increase due to the greater wing tip vortices

- As a result, climb performance decreases as the aircraft leaves ground effect

- Ground effect may allow the aircraft to become airborne before reaching the recommended take off safety speed. While it may be able to fly in ground effect, it will be unable to climb out of it

Ground Effect – Summary

- The 2 main results of ground effect are:
  - An increase in the lifting ability of the wing (increased C_L)
  - A reduction in drag (less formation of vortices and less induced drag)

- Both of these cause a floating effect near the ground