CPL Theory
Aerodynamics (CADA)

CAE Oxford
Aviation Academy

CADA 4 – Straight and Level Flight

Document Identification	
Document Category	Training Material
Document Revision Number	
Document Issue Date	
Document Status	Draft
Document Title	
Document Identification	MBWTRG-TRM-XXX

2. Related Documents

Related Documents	Document Identification

CADA 4 – Straight and Level Flight

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

DEFINITIONS

Some Relevant Definitions

Range

- The distance the aircraft travels over the ground.

Endurance

- The time the aircraft stays in the air.

Specific Air Range (SAR)

- The AIR nautical miles travelled for every litre of fuel burnt (TAS/FF) or (FF/TAS)

Specific Ground Range (SGR)

- The GROUND nautical miles travelled for every litre of fuel burnt (GS/FF) or (FF/GS)

Specific Fuel Consumption

- FF/Power (lb / hr / h.p)

Full Throttle Height

- A power setting at a height at which the butterfly is wide open

Volumetric Efficiency

- VE is the ratio of air entering the cylinder vs actual cylinder capacity

$$VE = \frac{\text{Actual amount of charge (by Weight) in cylinder}}{\text{Maximum amount of charge (by Weight) in cylinder @ ISA @ SL}}$$

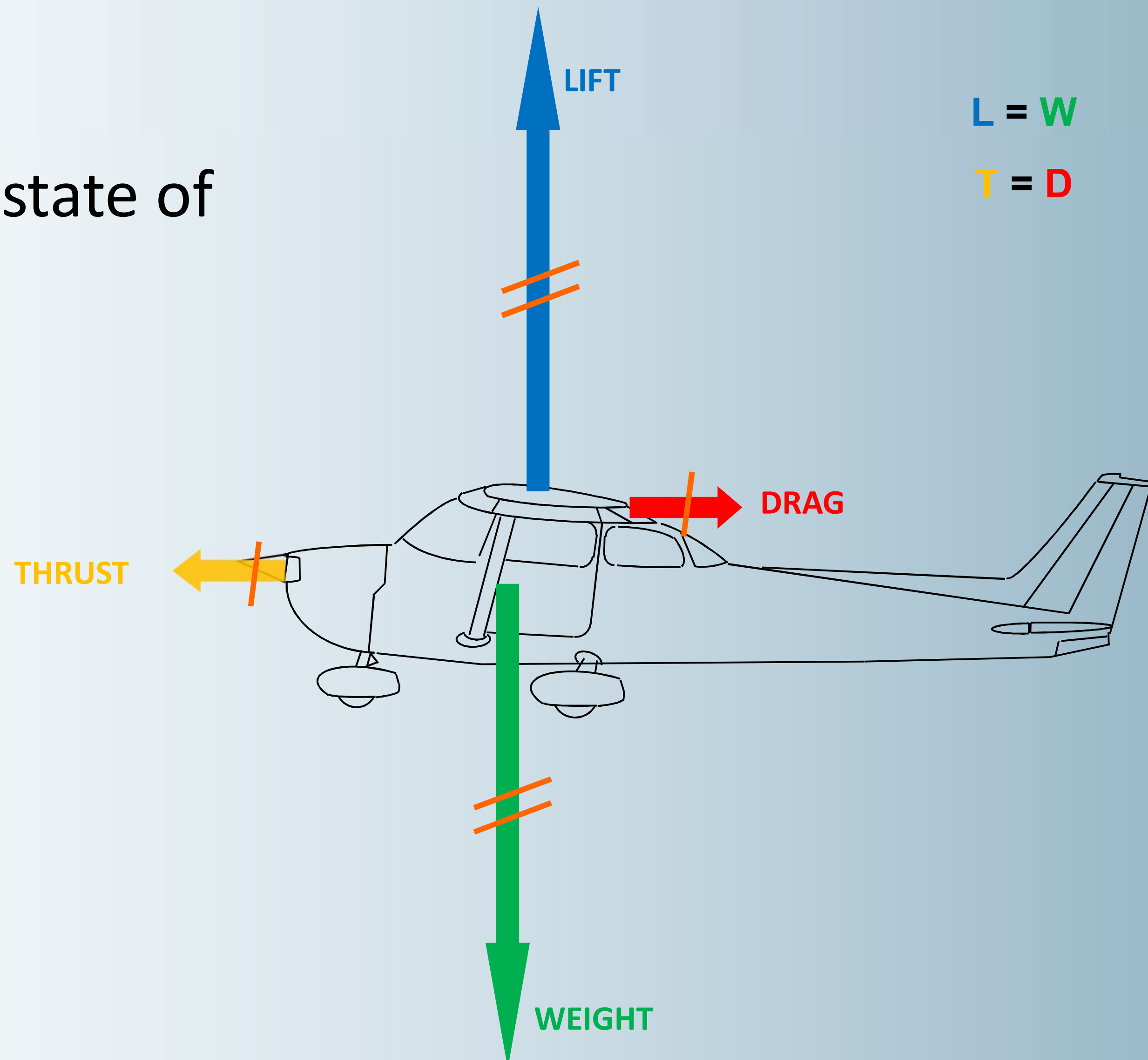
- **VE is maximum at Full Throttle Height** (for selected Power setting)
- Typically, un-tuned normally aspirated engines have VE of 70-80% at Full Throttle Height
- A turbocharged engine is capable of 100% (or more)

EQUALIBRIUM & MOMENTS

Equilibrium

Aircraft is in a state of

<u>equilibrium</u>

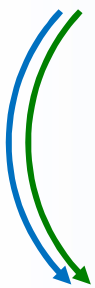


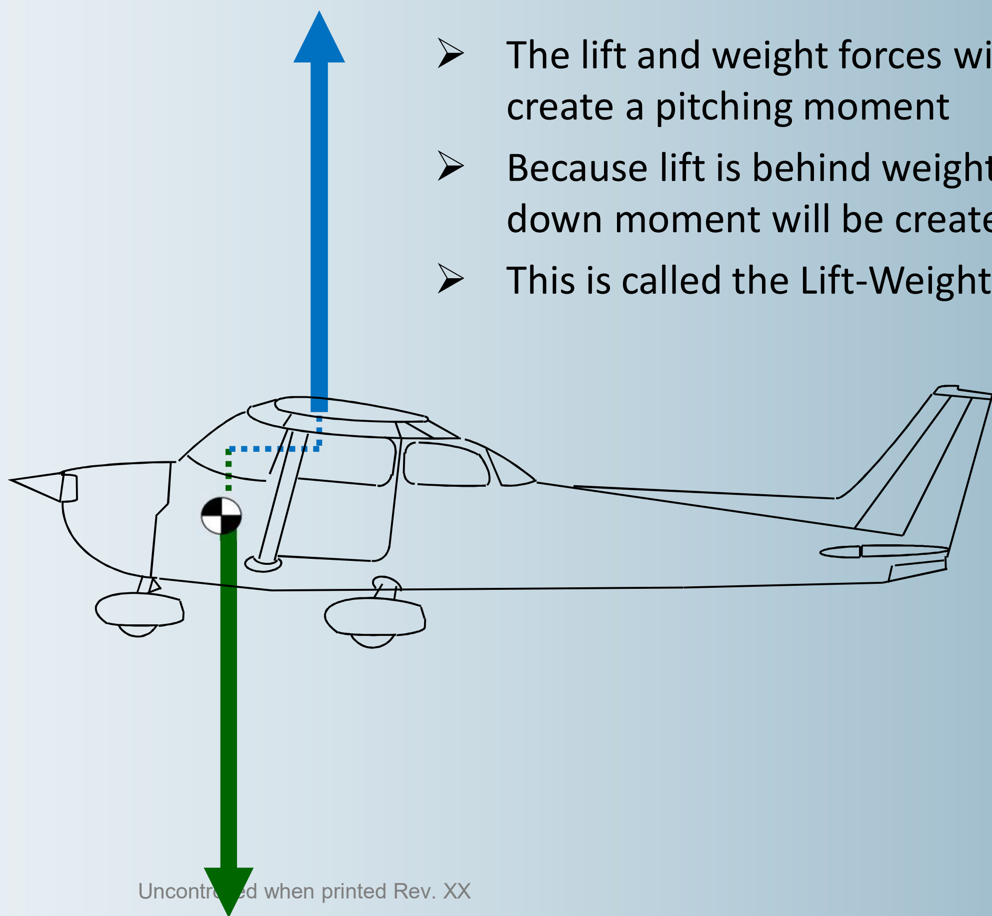
Coupling and Moments

A couple is caused by the interaction of two moments separated by a horizontal distance.

- The lift and weight forces will couple to create a pitching moment
- Because lift is behind weight, a nose down moment will be created
- This is called the Lift-Weight couple

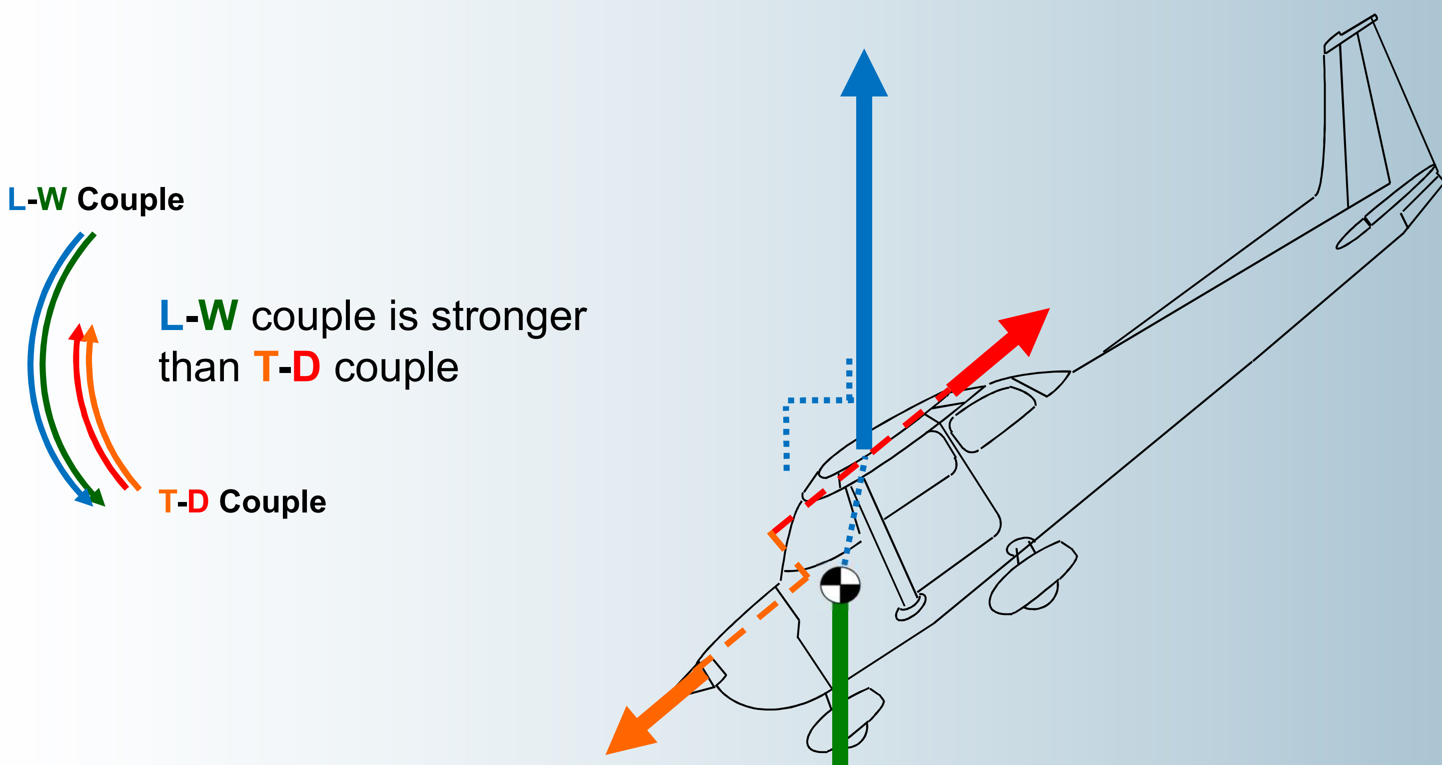
L-W Couple





Coupling and Moments

- The Thrust and Drag forces also form a couple together
- Because Drag is generally above thrust, the Thrust-Drag couple will produce a nose up moment
- The Thrust-Drag couple is not as strong as the Lift-Weight couple, so the aeroplane will still tend to pitch down



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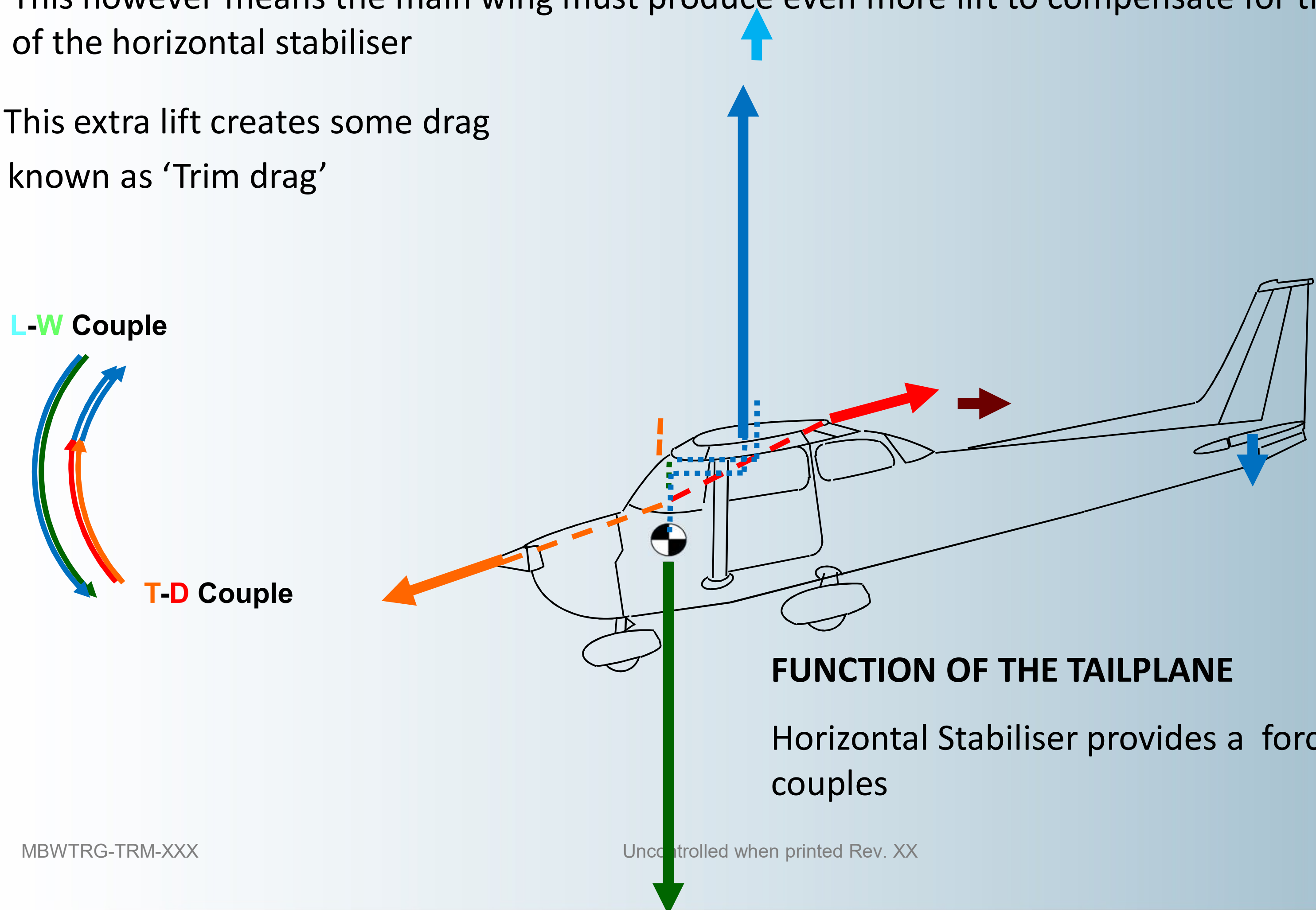
- To counter this nose down pitching moment, on most aeroplane the horizontal stabiliser provides a slight down force to restore the aircraft to equilibrium
- This however means the main wing must produce even more lift to compensate for the down force of the horizontal stabiliser
- This extra lift creates some drag known as 'Trim drag'



FUNCTION OF THE TAILPLANE

Horizontal Stabiliser provides a force to balances the couples

FACTORS AFFECTING LIFT

Lift

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

Factors affecting the Coefficient of lift:

- Wing shape
- Wing AOA

Factors affecting the Density of the air:

- Pressure height
- Temperature
- Humidity

Velocity = TAS

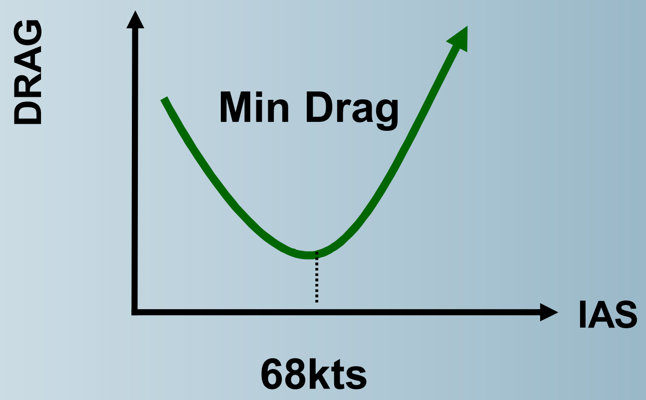
Note: V^2 means that is V is doubled, lift is quadrupled!

Planform area of the wing when the chord line is horizontal

RANGE AND ENDURANCE

Achieving Maximum Range

Maximum range occurs at best Lift/Drag Ratio. Since Lift is a constant the best L/D occurs at Min Drag.



- You have a given amount of energy stored in the fuel, so you can conduct a given amount of work
- Work done = Force(thrust) x Distance
- If you minimise the Force require, you can maximise the distance
- Fly at minimum drag speed (L/D max, Glide speed)

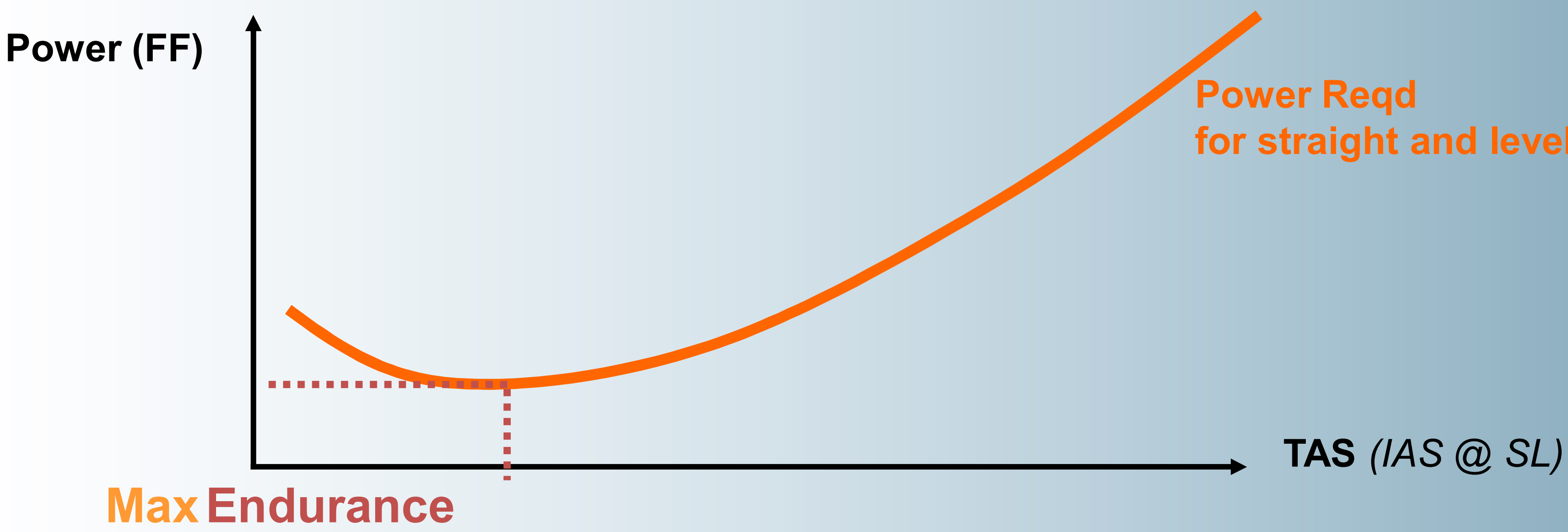
WORK (FUEL) (ENERGY)	=	FORCE (THRUST/ DRAG)	X	DISTANCE
12	=	6	X	2
12	=	4	X	3
12	=	3	X	4
12	=	2	X	6

Therefore, Max range occurs when total drag is minimum.

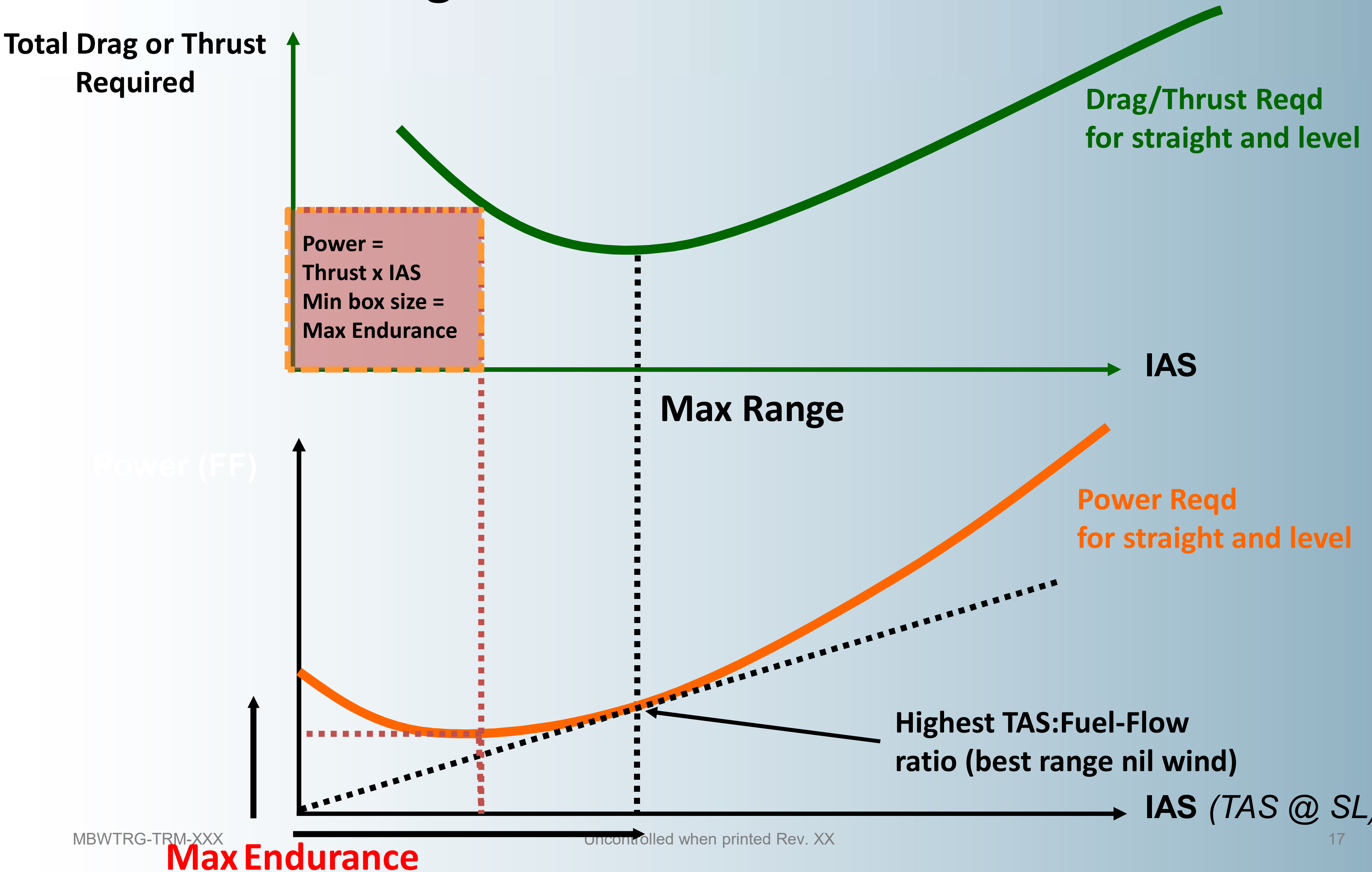
Achieving Maximum Endurance

Endurance is dependant on minimum fuel flow to allow for greatest air time.

- Minimum fuel flow occurs when minimum power is required for straight and level flight.
- **Therefore**, Max Endurance occurs at the speed for minimum power.
- Note: This speed will be LESS than minimum drag speed



Maximum Range vs Maximum Endurance

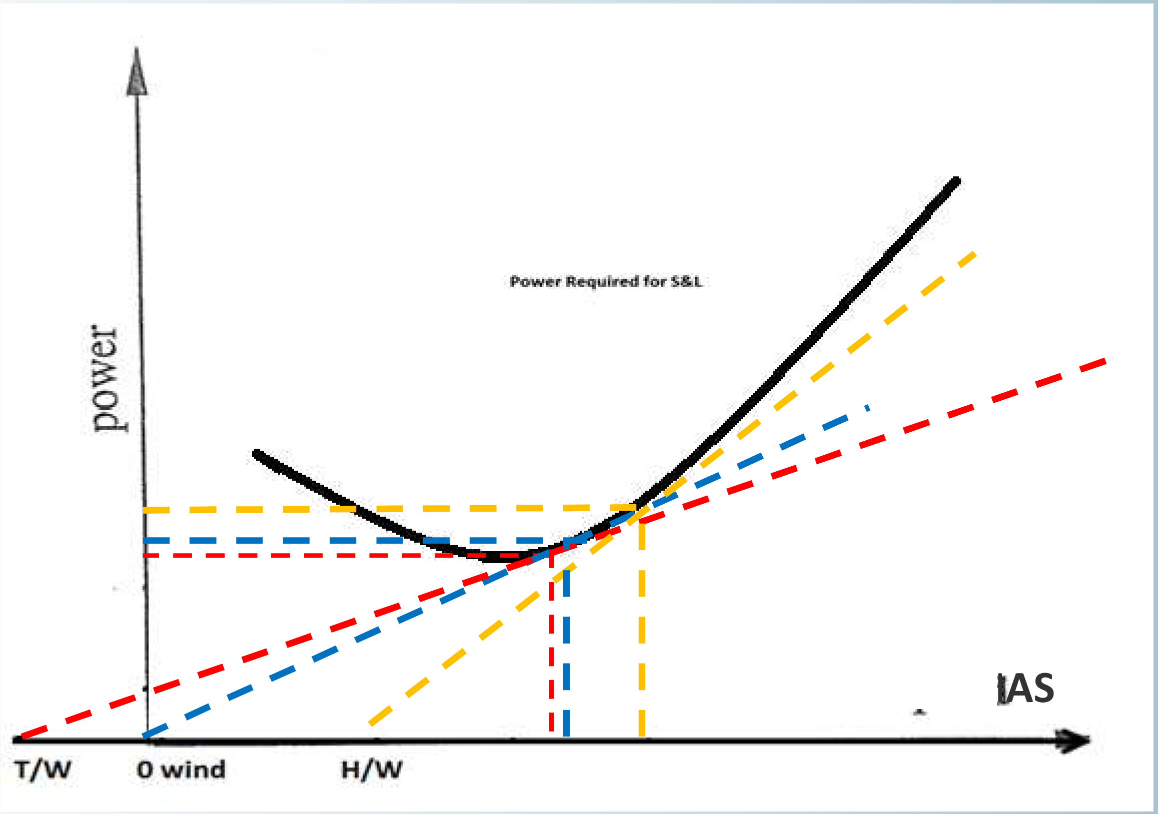


RANGE AND ENDURANCE CONSIDERATIONS

CADA 4 – Straight and Level Flight

	Endurance	Range
Headwind ↑		
Tailwind ↑		
Weight ↑		
Weight ↓		
Airspeed ↑↓		
Altitude ↑		
Altitude ↓		

Effect of Wind on Range

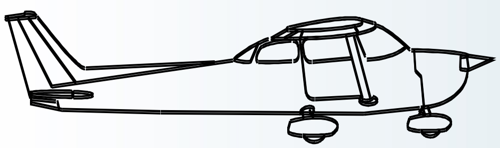


Headwind	=	decreased range – fly at a faster speed
Tailwind	=	increased range – fly at a slower speed

Effect of Wind on Endurance

Endurance is the time spent in the air…

So if there was a HW… and if there was a TW…



It wouldn't affect the time you spend in the air

It still doesn't affect the time you spend in the air

But remember that it does affect the distance you travel over the ground (**Range**)

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	Endurance	Range
Headwind ↑	—	↓
Tailwind ↑	—	↑
Weight ↑		
Weight ↓		
Airspeed ↑↓		
Altitude ↑		
Altitude ↓		

Effect of Weight

Pilots Lift Formula

W = L ∞ AoA $\times$ IAS (x Power ∞ Fuel Flow)

Summary

Increased Weight	=	More Lift Required (Increased Thrust + Drag)	Range ↓
Decreased Weight	=	Less Lift Required (Decreased Drag)	Range ↑
Increased Weight	=	Increased Power Required (Greater FF)	Endurance ↓
Decreased Weight	=	Decreased Power Required (Lower FF)	Endurance ↑

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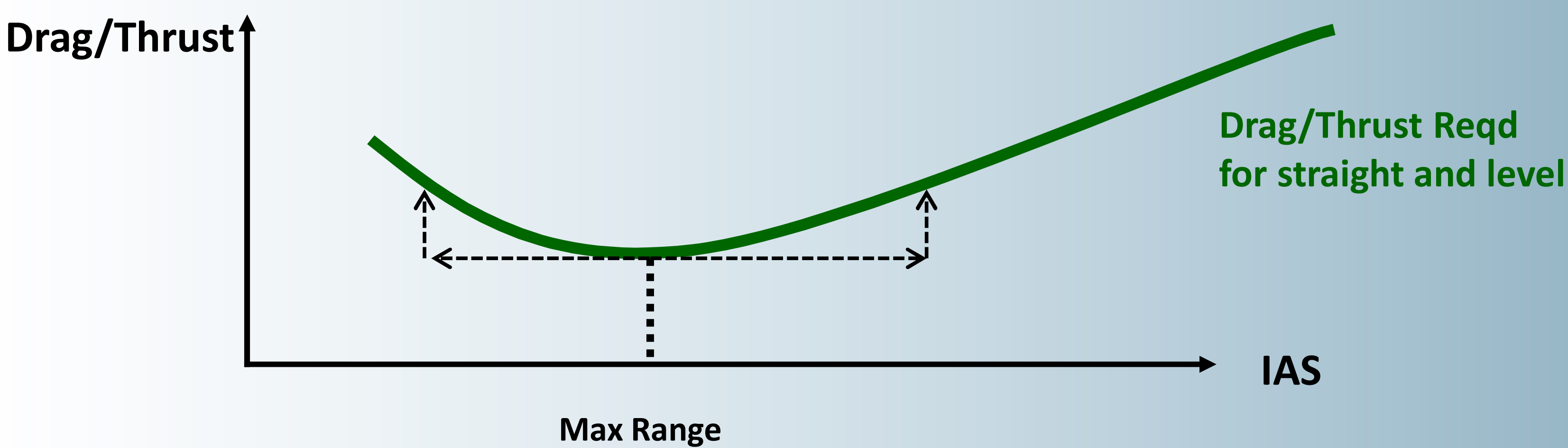
	Endurance	Range
Headwind ↑	—	↓
Tailwind ↑	—	↑
Weight ↑	↓	↓
Weight ↓	↑	↑
Airspeed ↑↓		
Altitude ↑		
Altitude ↓		

Effect of Airspeed on Range

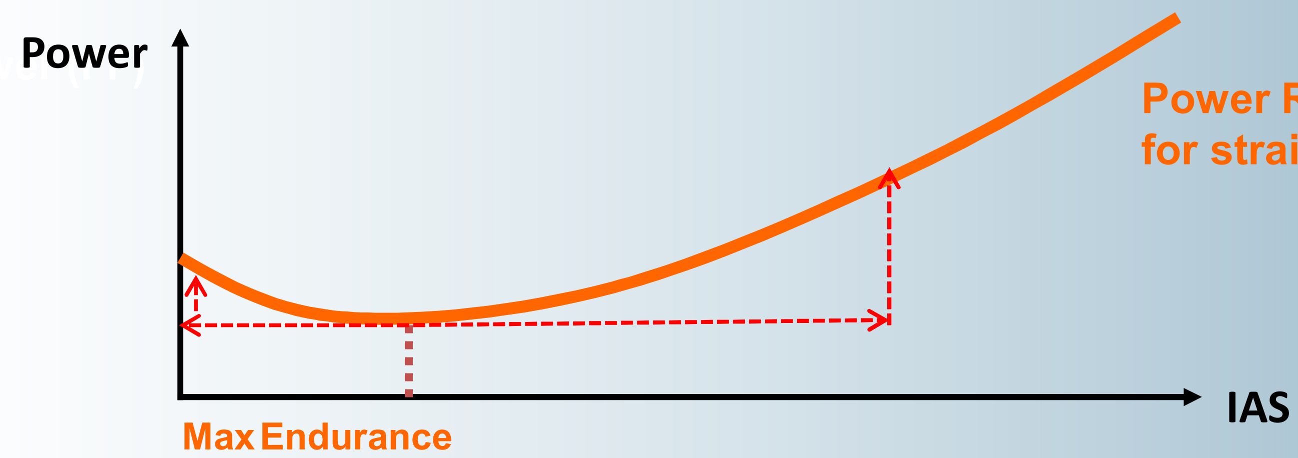
- Any deviation from the minimum drag airspeed will result in a rise in drag
- Any rise in drag will result in decreased range



Increase IAS	=	Increased Drag	Range ↓
Decreased IAS	=	Increased Drag	Range ↓

Effect of Airspeed on Endurance

- Any deviation from the minimum power airspeed will result in a rise in power required
- Increased power required results in increased fuel-flow
- This results in your fuel being burnt quicker and your endurance reduces



Increase IAS	=	Increased Power Required	Endurance ↓
Decreased IAS	=	Increased Power Required	Endurance ↓

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	Endurance	Range
Headwind ↑	—	↓
Tailwind ↑	—	↑
Weight ↑	↓	↓
Weight ↓	↑	↑
Airspeed ↑↓	↓	↓
Altitude ↑		
Altitude ↓		

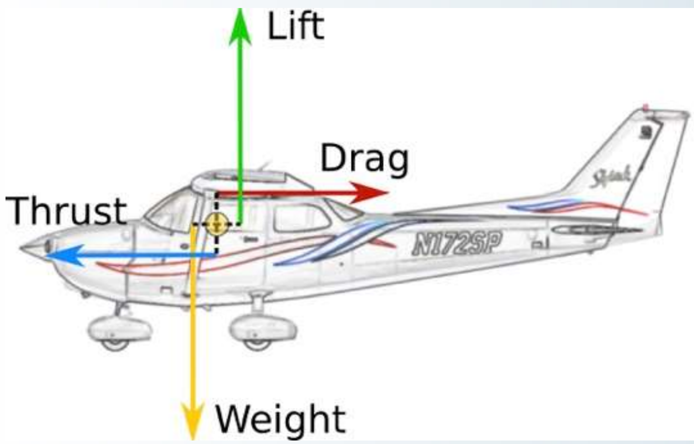
Effect of Airframe and Altitude on Range

Airframe Efficiency

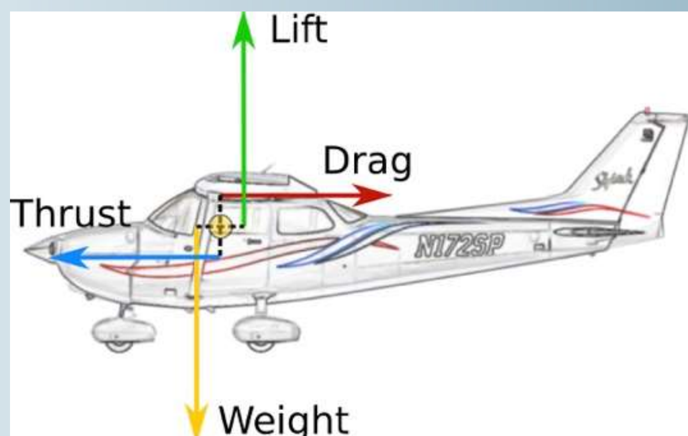
Greatest at best L/D ratio

L/D Ratio independent of altitude - and thrust required constant

However, because the air is less dense we need to be going faster to displace our same weight in air molecules.



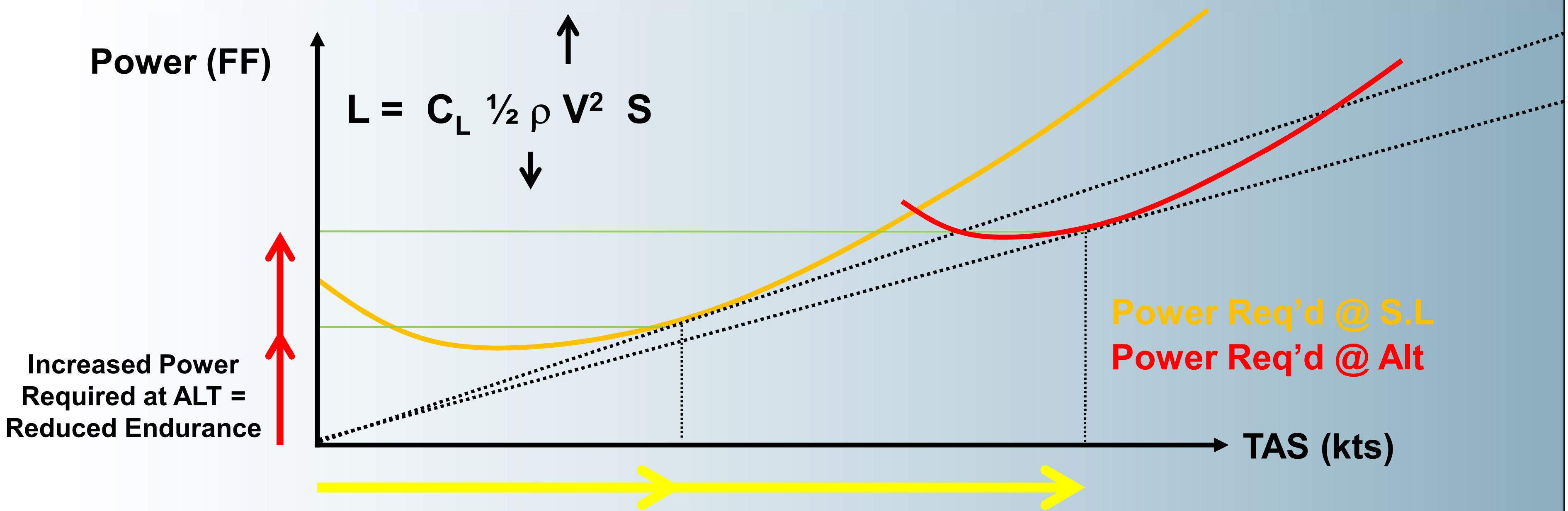
Thrust require @ SL



Thrust require @ Alt

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

Effect of Airframe and Altitude on Endurance



Observe: Greater ↑ in **Range** compared to ↑ Power (FF)

@ S.L

@ Alt

Effect of Airframe and Altitude on Endurance

Range

Increase Altitude =	Higher TAS For Same Drag	Range ↑
Decrease Altitude =	Lower TAS For Same Drag	Range ↓

Endurance

Increase Altitude =	Greater power required	Endurance ↓
Decrease Altitude =	Reduced power required	Endurance ↑

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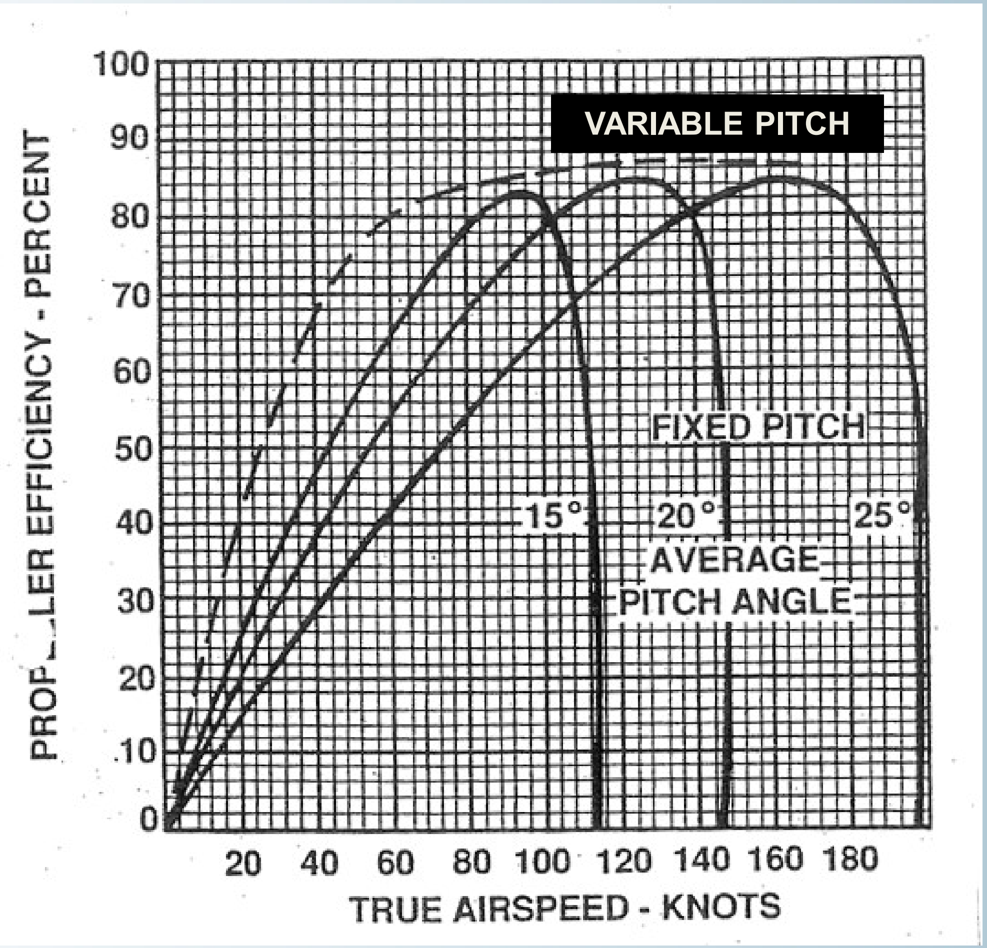
	Endurance	Range
Headwind ↑	—	↓
Tailwind ↑	—	↑
Weight ↑	↓	↓
Weight ↓	↑	↑
Airspeed ↑↓	↓	↓
Altitude ↑	↓	↑
Altitude ↓	↑	↓

Effect of Propeller Efficiency on Endurance

Fixed pitch is only efficient with one TAS (AoA).

Variable pitch maintains high efficiency over wide range of airspeed.



Effect of Engine Efficiency on Endurance

Specific Fuel Consumption shows engine efficiency.

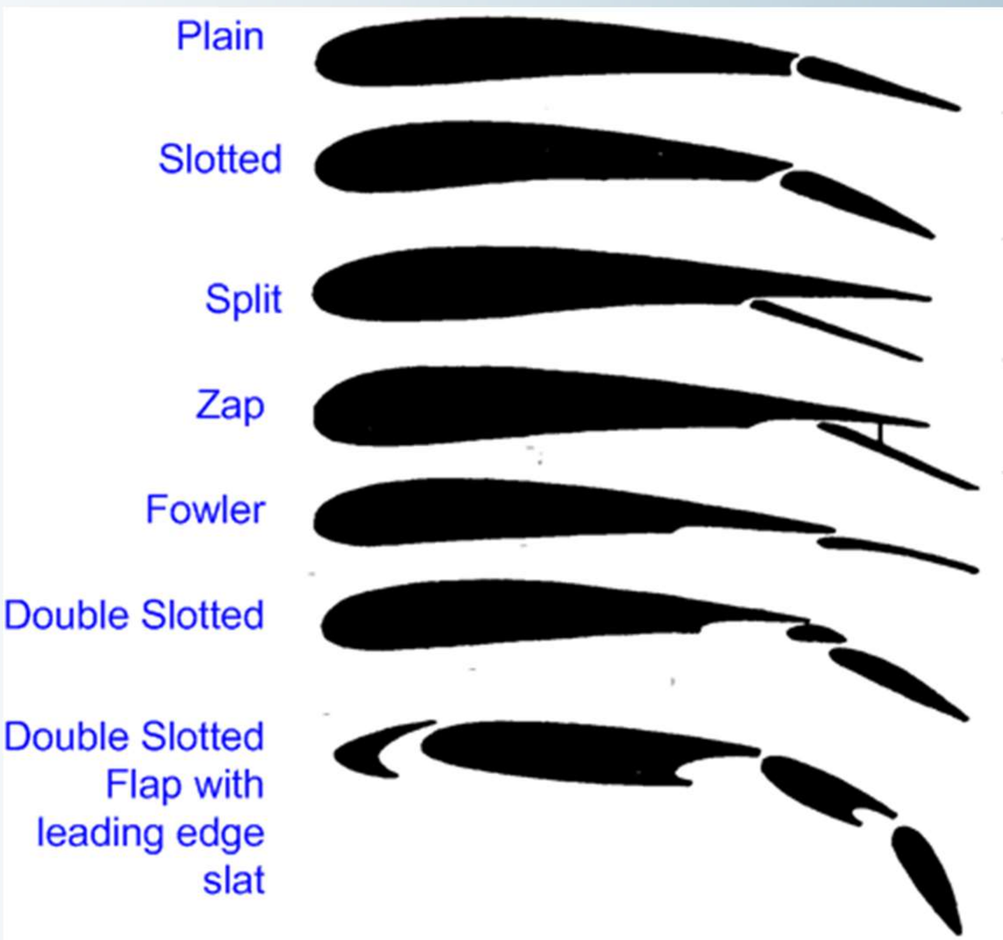
= FF / POWER

When the ratio of fuel flow to power generated is least – engine efficiency is maximised.

LIFT AUGMENTATION DEVICES

Flaps

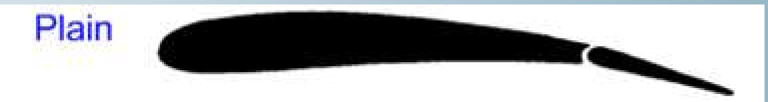
Like the ailerons, the flaps can also have specific design features



Flaps

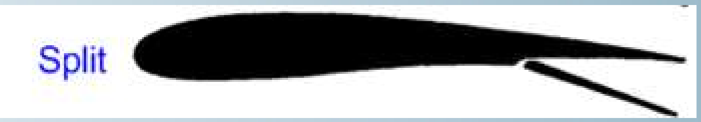
Plain Flap

- Increases the effective camber
- Useful for lift increases
- Generates high drag when fully extended



Split Flap

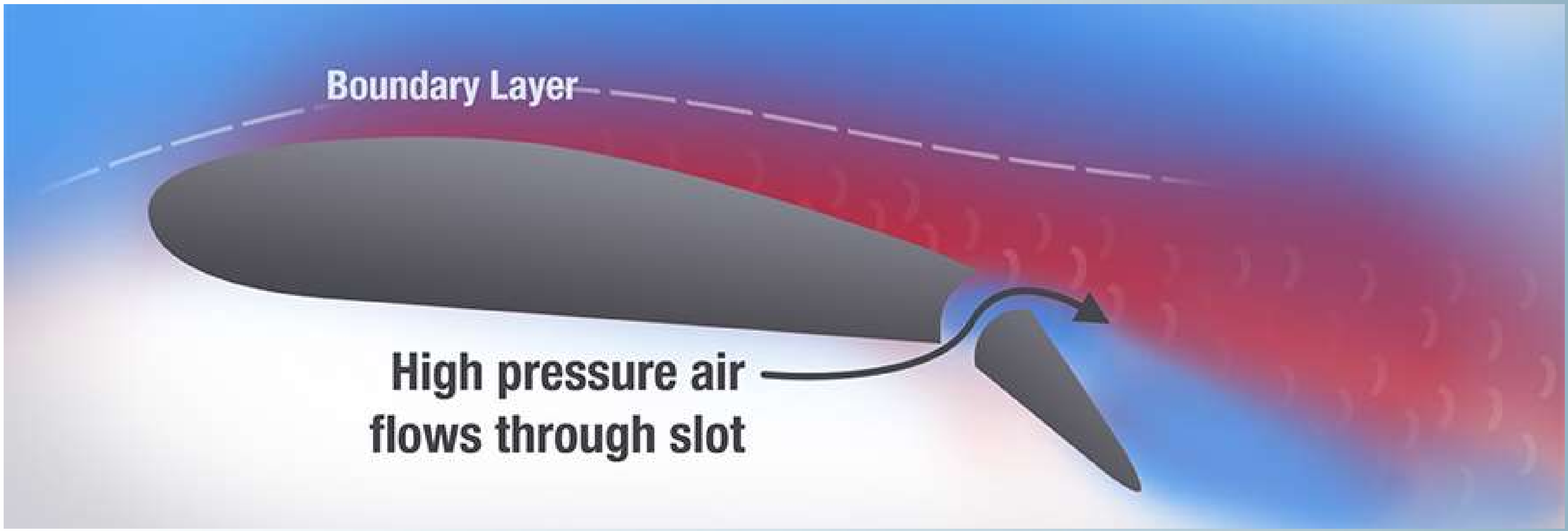
- Produces high drag
- Useful for control of airspeed during approach and landing



Flaps

Fowler Flap

- Very good at producing lift
- Designed to move rearwards when extending as well as down
- Results in a small increase of surface area
- Allows high pressure air to reenergise the boundary layer and delays:
  - The breakdown of laminar flow into turbulence
  - The separation of the boundary layer from the upper surface



Flaps

Double-Slotted Fowler Flap

- Very good at producing lift
- Similar to the fowler flap however extends further out
- This results in further effects to the fowler flap