AIRCRAFT PERFORMANCE ATPL AB-INITIO

ELYES HACHICHA

53 hours

I) INTRODUCTION
II) GENERAL PRINCIPLES
III) CLASS B: SINGLE ENGINE
IV) CLASS B: MULTI ENGINED
V) CLASS A AIRCRAFT

I) INTRODUCTION

II) GENERAL PRINCIPLES

A) Take Off
B) Climb and Descent
C) Cruise
D) Landing

III) CLASS B: SINGLE ENGINE

A) Take Off
B) Climb
C) En-route & Descent
D) Landing

IV) CLASS B: MULTI ENGINED

A) Take Off
B) Climb
C) En-route & Descent
D) Landing

V) CLASS A AIRCRAFT

A) Take Off
B) Additional Take Off Procedures
C) Take Off Climb
D) En Route
E) Landing

I) INTRODUCTION

PERFORMANCE CLASS A

- Multi-engined aeroplanes powered by turbo-propeller engines with a maximum approved passenger seating configuration of more than 9 or a maximum take-off mass exceeding 5700 kg
- All multi-engined turbo-jet powered aeroplanes.

Class A aeroplanes must comply with the Certification Specifications in the document from EASA called **CS-25.**

PERFORMANCE CLASS B

- Propeller driven aeroplanes with a maximum approved passenger seating configuration of 9 or less, and a maximum take-off mass of 5700 kg. or less.

Class B aeroplanes must comply with the Certification Specifications in the document from EASA called **CS-23**.

PERFORMANCE CLASS C

- Aeroplanes powered by reciprocating engines with a maximum approved - passenger seating configuration of more than 9 or a maximum take-off mass exceeding 5700 kg

	Multi-engined Jet	Propeller driven	
		Multi-engined Turbo-Prop	Piston
Mass: > 5700 kg Or PAX Seats: > 9	A	A	C
Mass: ≤5700 kg And PAX Seats: ≤ 9	A	B	B

UNCLASSIFIED

This class is given to those aeroplanes whose performance characteristic is very unique and special performance consideration is required.

For example, the Unclassified class includes supersonic aeroplanes and sea planes.

PERFORMANCE EXPRESSIONS

Any class of aeroplane, operated in the public transport role must adhere to the operational requirements set out in EU-OPS.

- **MEASURED PERFORMANCE**

Performance measured during testing with different conditions and technics

- **GROSS PERFORMANCE**

Gross Performance is the average performance

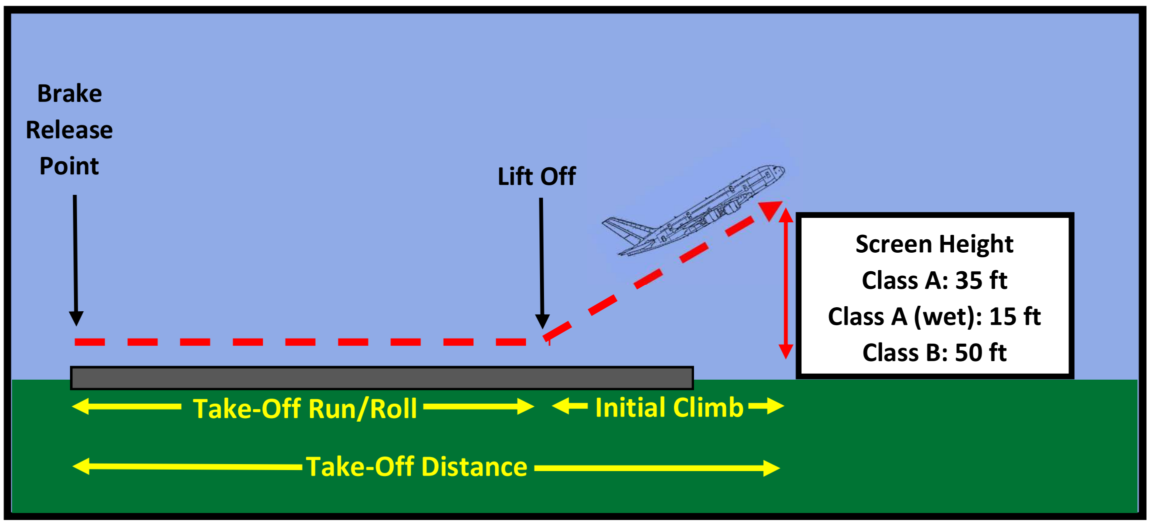
- **NET PERFORMANCE**

Net performance is the gross performance diminished

II) GENERAL PRINCIPLES

A) Take Off (T/O)

The take off part of the flight is the distance from the brake release point (BRP) to the point at which the aircraft reaches a defined height. This defined height is called the “screen height”.
The screen height varies from 35 ft for class A aeroplanes to 50 ft for class B aeroplanes.



Available distances

- **TORA: T/O Run Available**

The length of runway declared available and suitable for the ground run of an aeroplane taking off.

- **TODA: T/O Distance Available**

The length of the take-off run available (TORA) plus the length of the clearway, where provided.

- **CLEARWAY (CWY)**

An area beyond the paved runway, free of obstructions and under the control of the airport authorities. The length of the clearway may be included in the length of the takeoff distance available (TODA). **CWY shouldn’t exceed 50% of TORA, not less than 152 m (500 ft) wide, extending from the end of the runway with an upward slope not exceeding 1,25%**

- **ASDA: Accelerated Stop Distance Available**

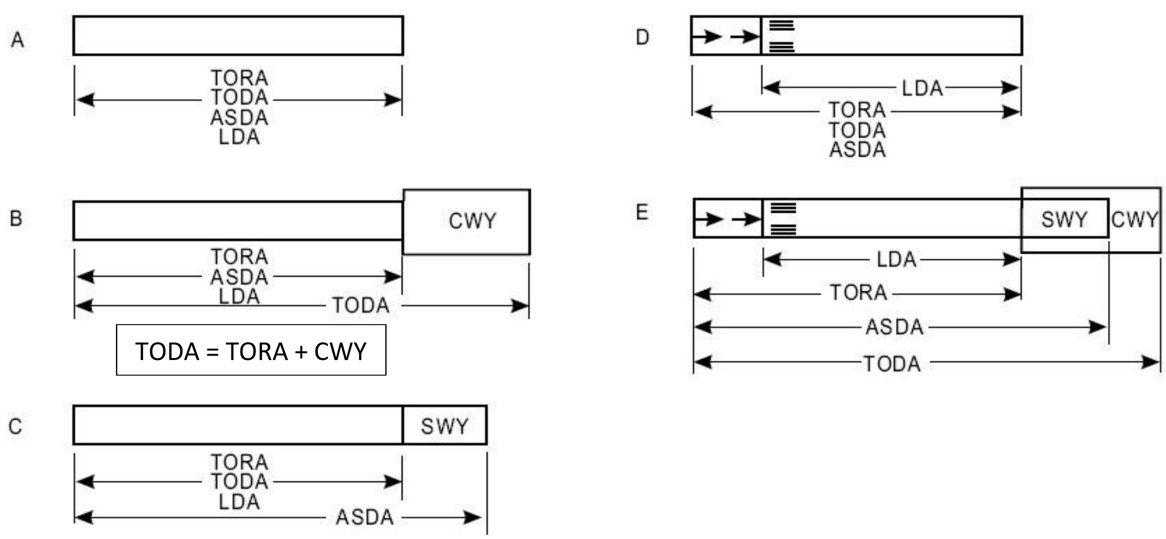
The length of the take-off run plus the length of the Stopway, where provided

- **STOPWAY (SWY)**

An area beyond the runway which can be used for deceleration in the event of a rejected takeoff. It must be:

- At least as wide as the runway
- Centred upon the runway extended centreline
- Capable of supporting the aeroplane during an aborted take-off without causing structural damage to the aircraft
- Designated by the airport authorities for use in decelerating the airplane during an aborted take-off

Stopways are identified by large yellow chevrons on either end of the main runway.



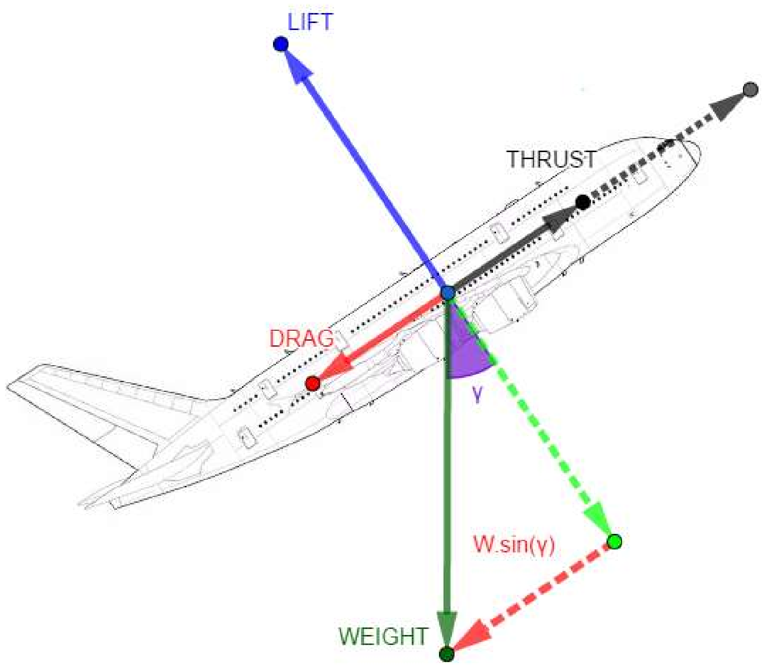
ASDA = TORA + SWY

Affecting factors

Factors	**Increase T/O distance**	**Decrease T/O distance**
Weight	Heavy	Light
Wind	Tailwind (use 150%)	Headwind (use 50%)
Config (flaps)	Flapless, high flaps set	Low or optimum flaps set
Density (pressure, temp, humidity)	High pressure alt. high temp, high humid	Low pressure alt. low temp, low humid
Runway surface	Grass, wet, damp, etc	Paved, dry
Airframe	Contaminated	Clear
Slope	Upslope **Increase 5% TOD for each 1% slope**	Downslope

B) Climb (CLB) & Descent (DESC)

1) Climb (CLB)



$$L < W$$

$$T > D$$

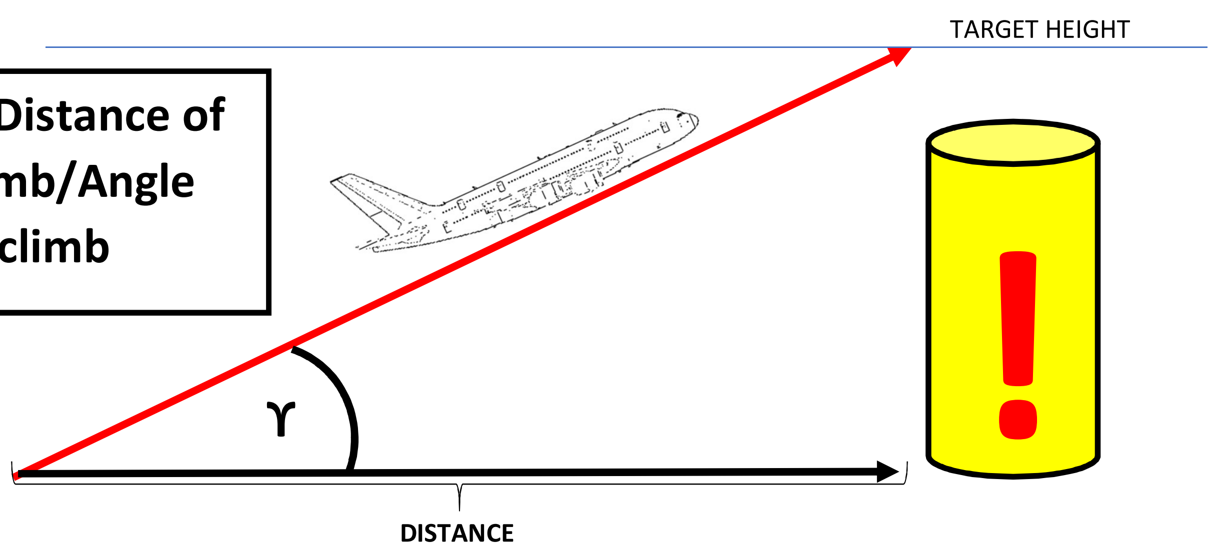
$$T = D + W.\sin\gamma$$

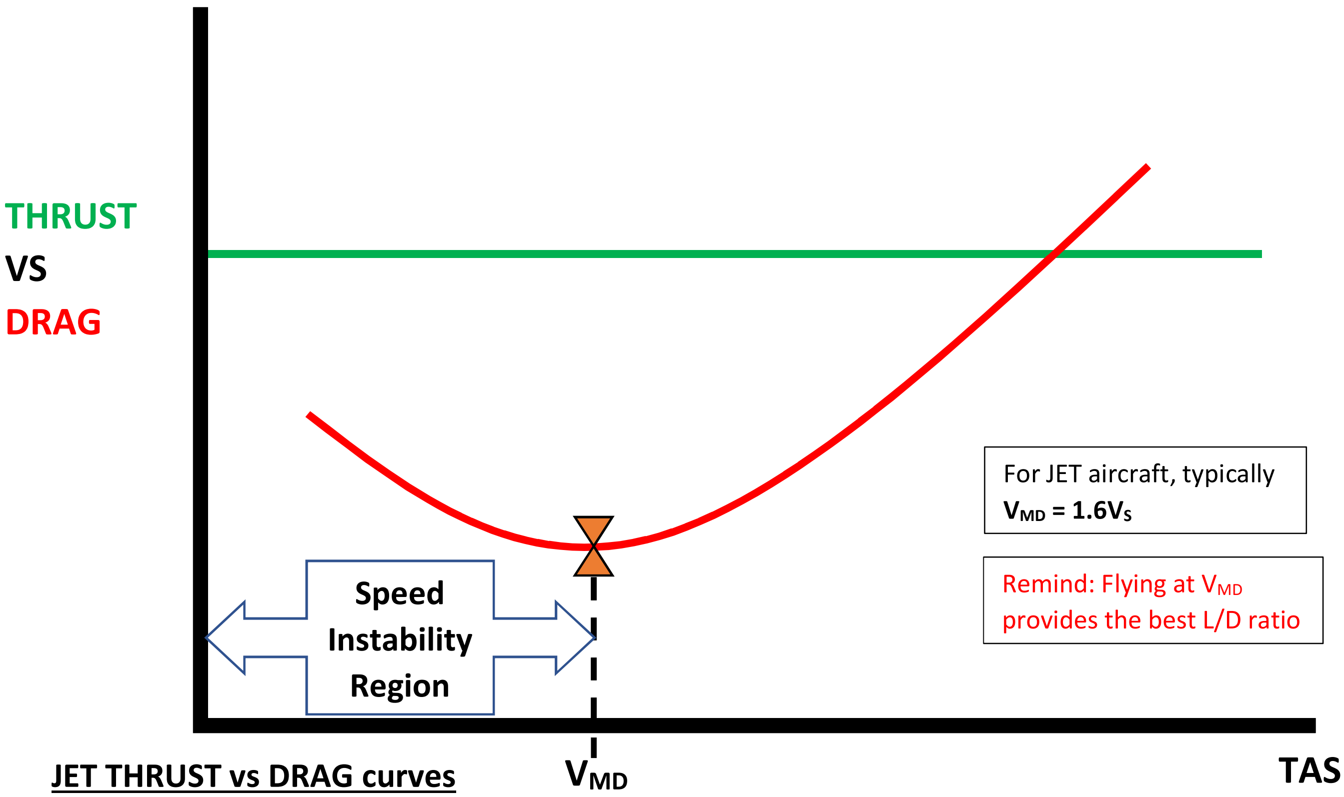
There are 2 ways to analyse a climb:

- Angle of climb (forward distance to reach a height)
- Rate of climb (time to reach height)

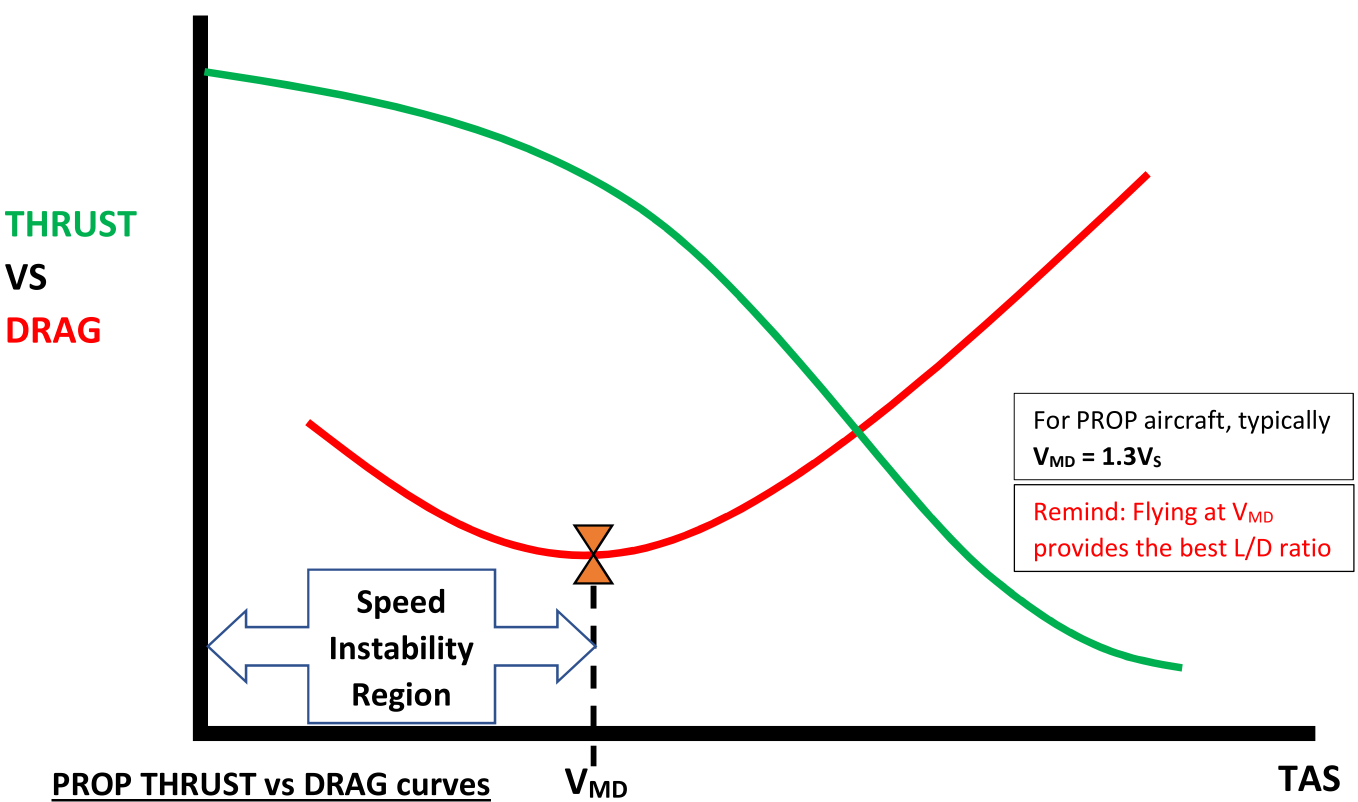
1.1) Angle of Climb

⚠ Distance of climb/Angle of climb

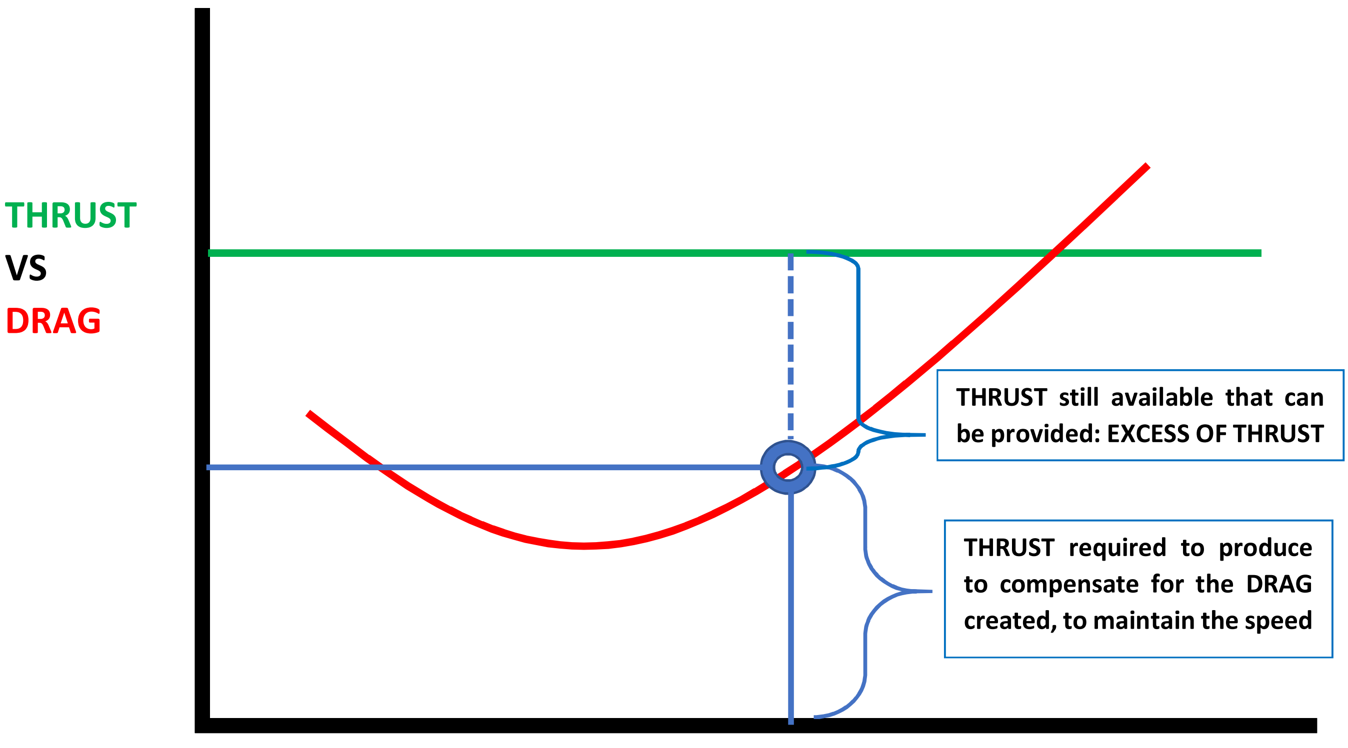




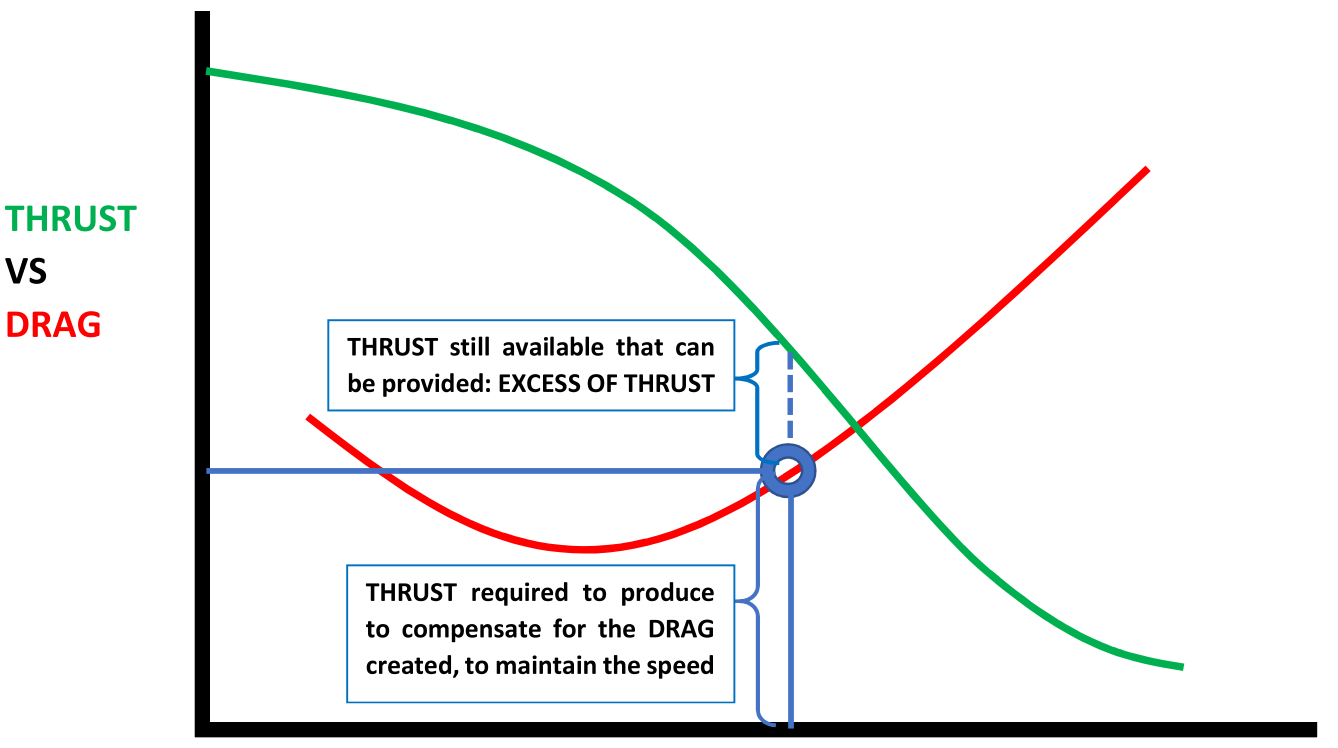
JET THRUST vs DRAG curves



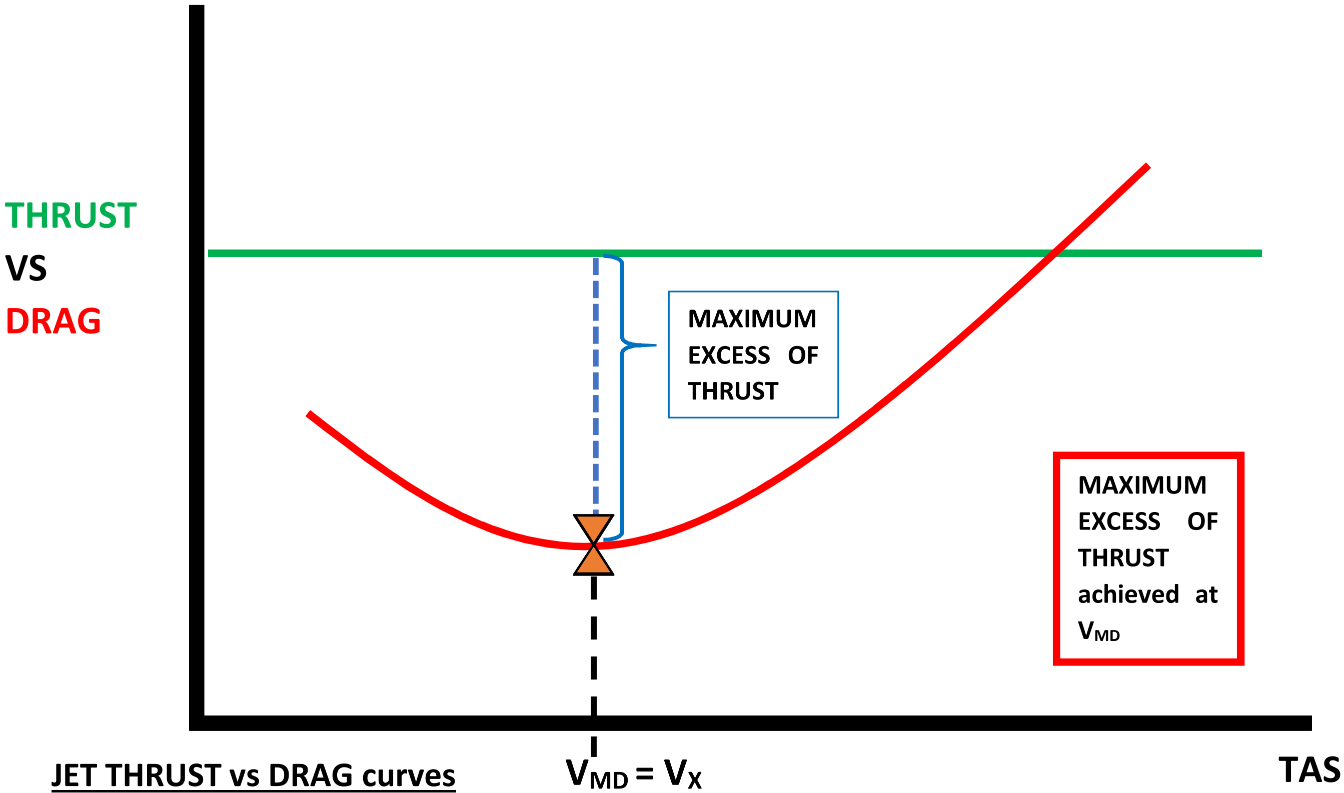
PROP THRUST vs DRAG curves



JET THRUST vs DRAG curves

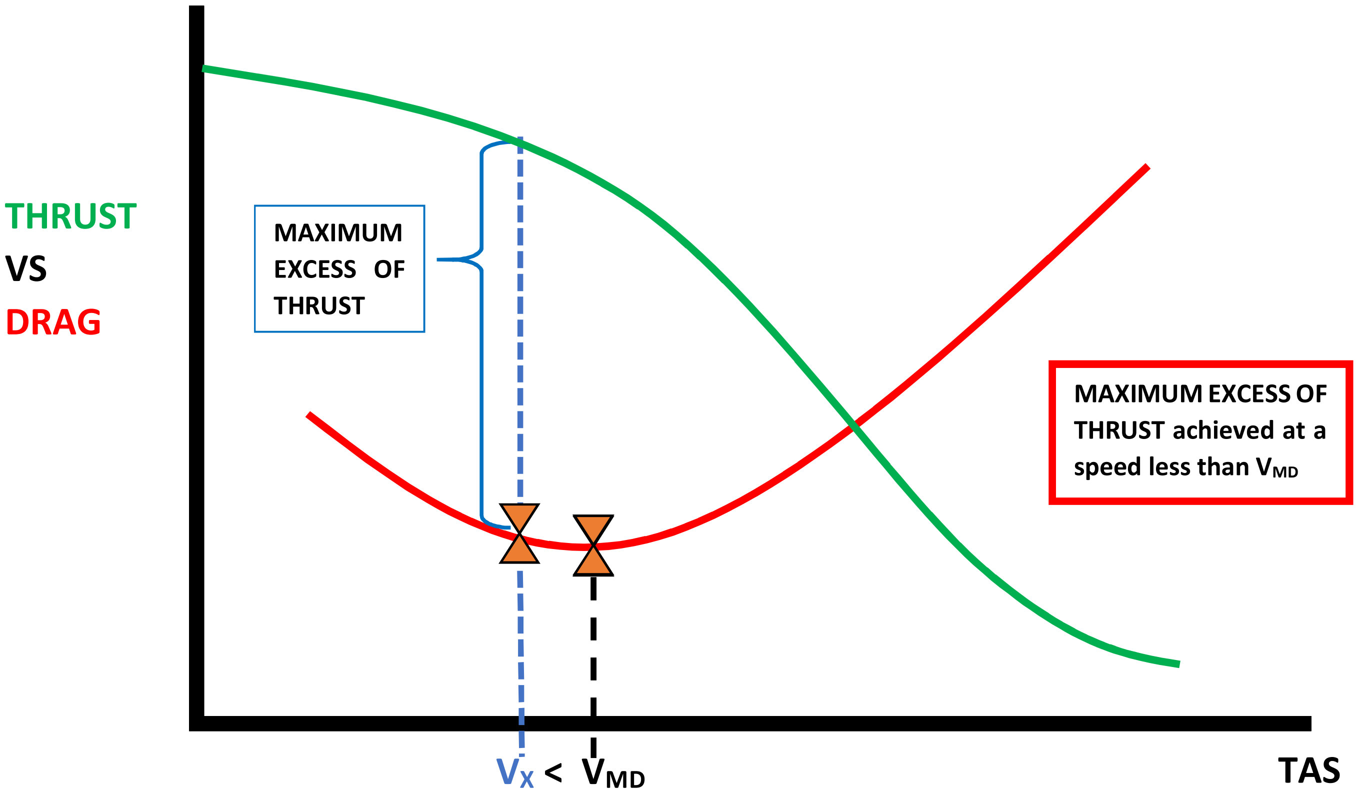


PROP THRUST vs DRAG curves



<u>**JET THRUST vs DRAG curves**</u>

V_X: Best angle of climb speed → For the JET engine, $V_X = V_{MD}$



PROP THRUST vs DRAG curves

V_X: Best angle of climb speed → For the PROP engine, $V_X < V_{MD}$

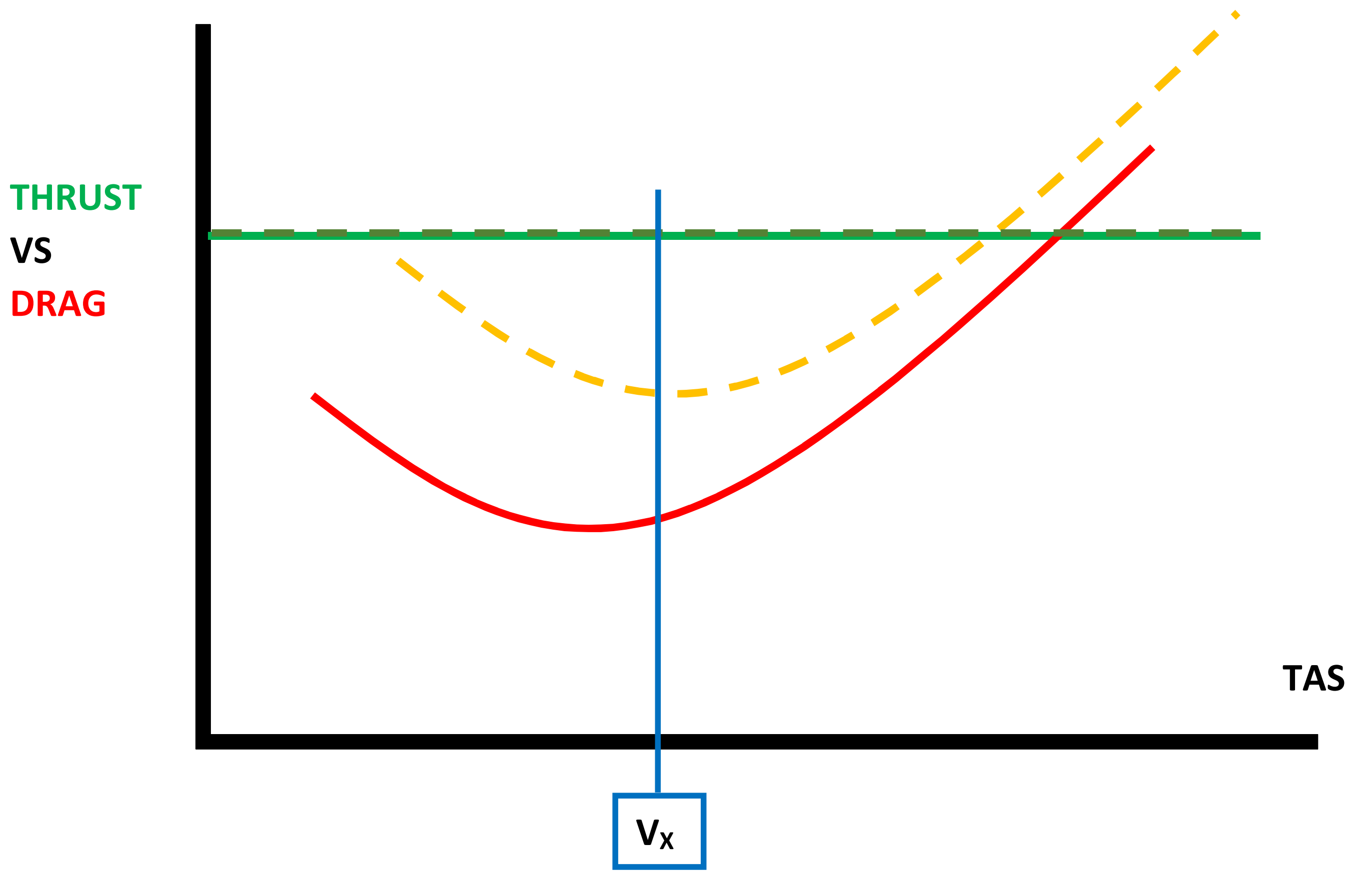
To calculate the Gradient of climb:

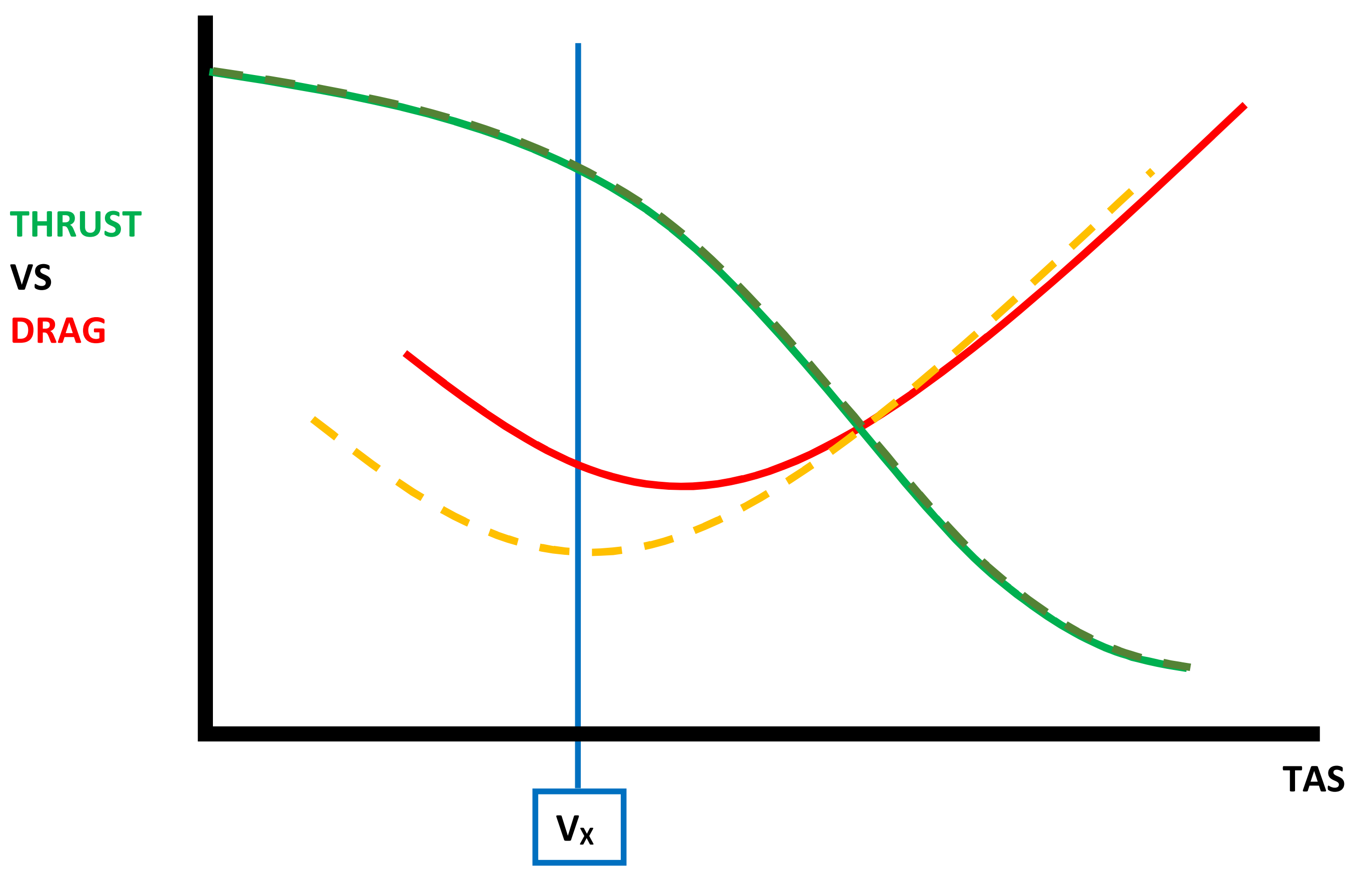
$$Gradient\ (\%) = \frac{Thrust - Drag}{Weight} X\ 100$$

$$Gradient\ (\%) = \frac{Excess\ of\ Thrust}{Weight} X\ 100$$

Affecting factors

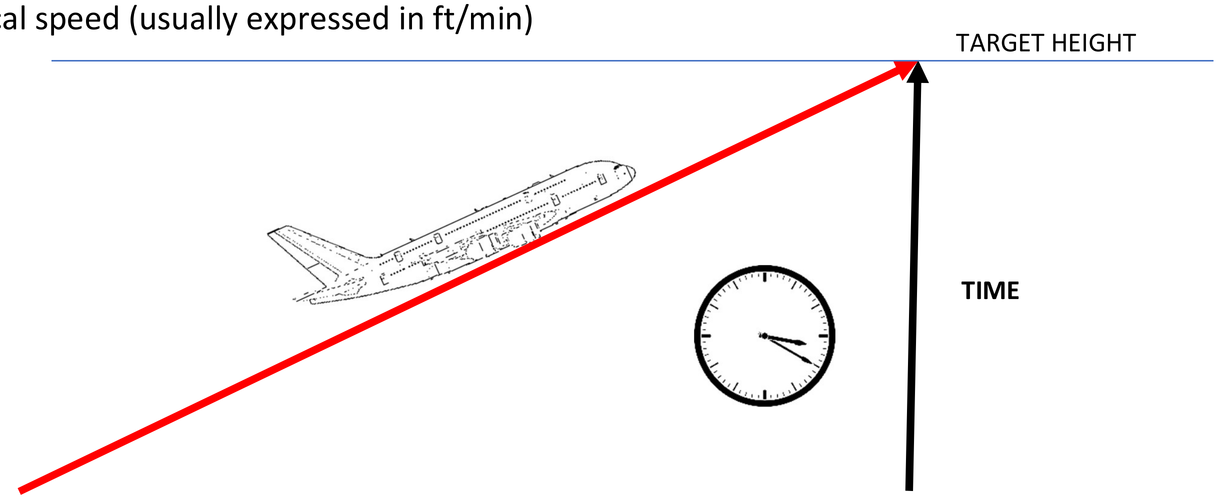
Factors	**Increase angle of climb**	**Decrease angle of climb**
Weight	Light (V_X ↓)	Heavy (V_X ↑)
Config (flaps)	Flaps retracted, gear up (V_X ↑)	Flaps extended, gear down (V_X ↓)
Density (pressure, temp)	Low pressure elev. Low temp	High pressure elev. High temp
Wind (TAS/GS x Gradient)	Headwind	Tailwind


THRUST
VS
DRAG
TAS
V_X


THRUST
VS
DRAG
TAS
V_X

1.2) Rate of Climb

Vertical speed (usually expressed in ft/min)



Mathematical basics:

Definition:

WORK: Results when a FORCE acts upon an object to a displacement (or motion)

$$Work = Force\ X\ distance$$

POWER: Rate at which a WORK is done upon an object

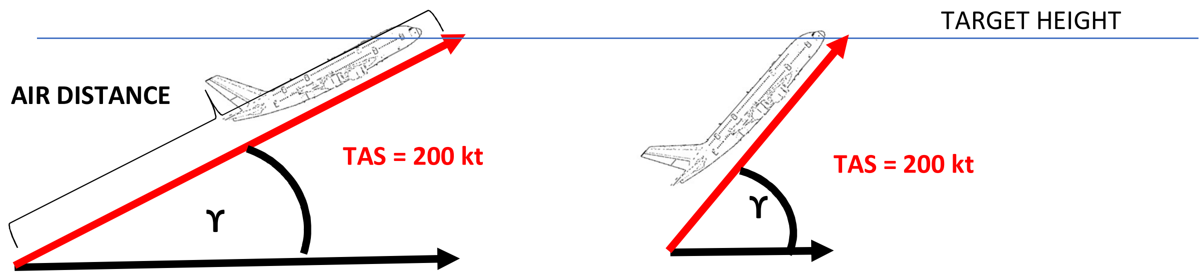
$$Power = \frac{Work}{time}$$

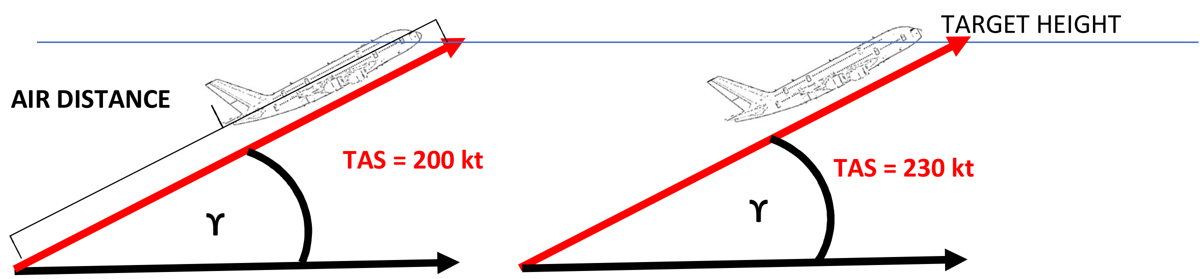
$$Power = \frac{Force\ X\ distance}{time}$$

$$Power = Force\ X \frac{distance}{time}$$

$$Power = Force\ X\ v$$

ROC parameters



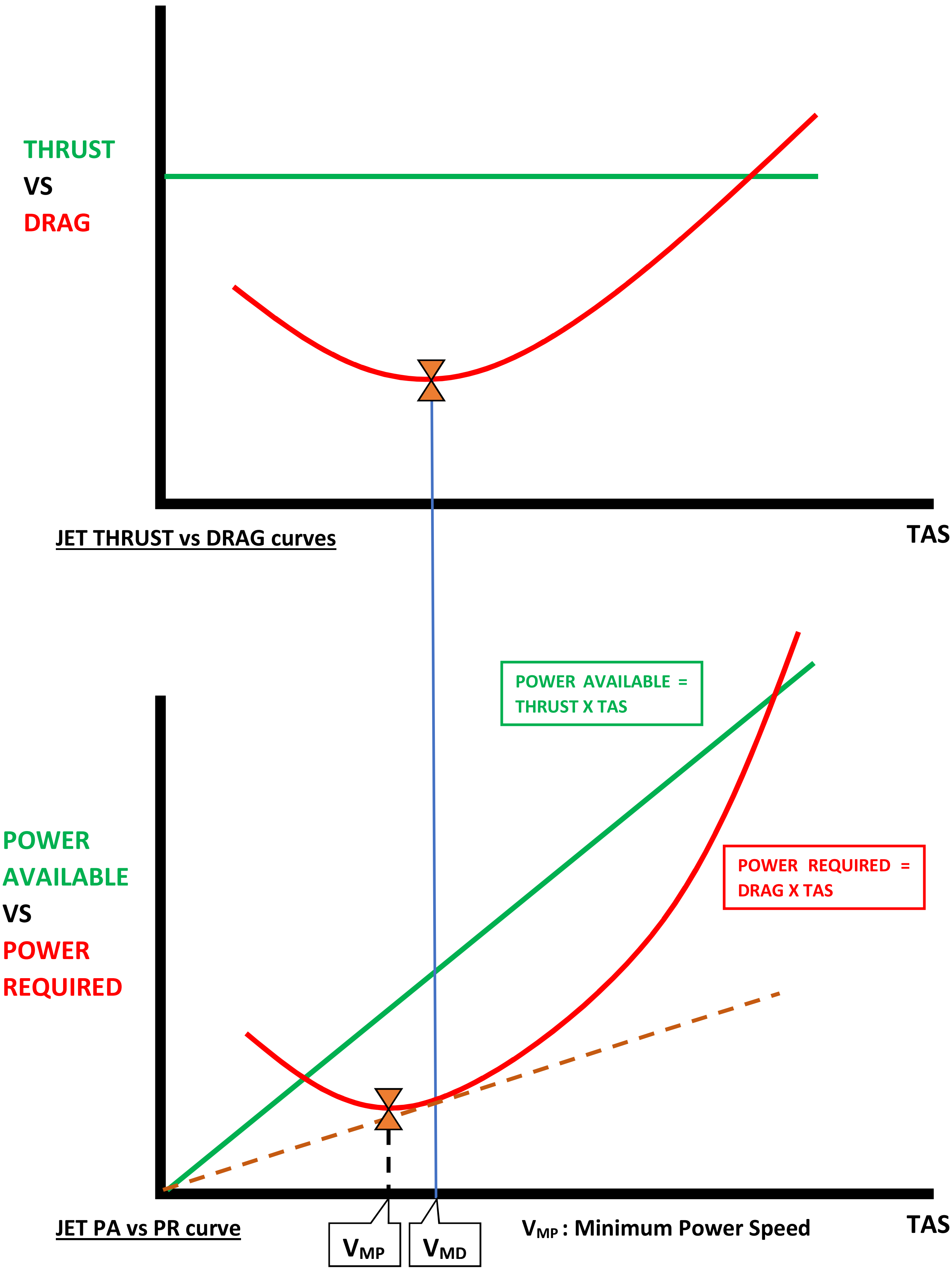


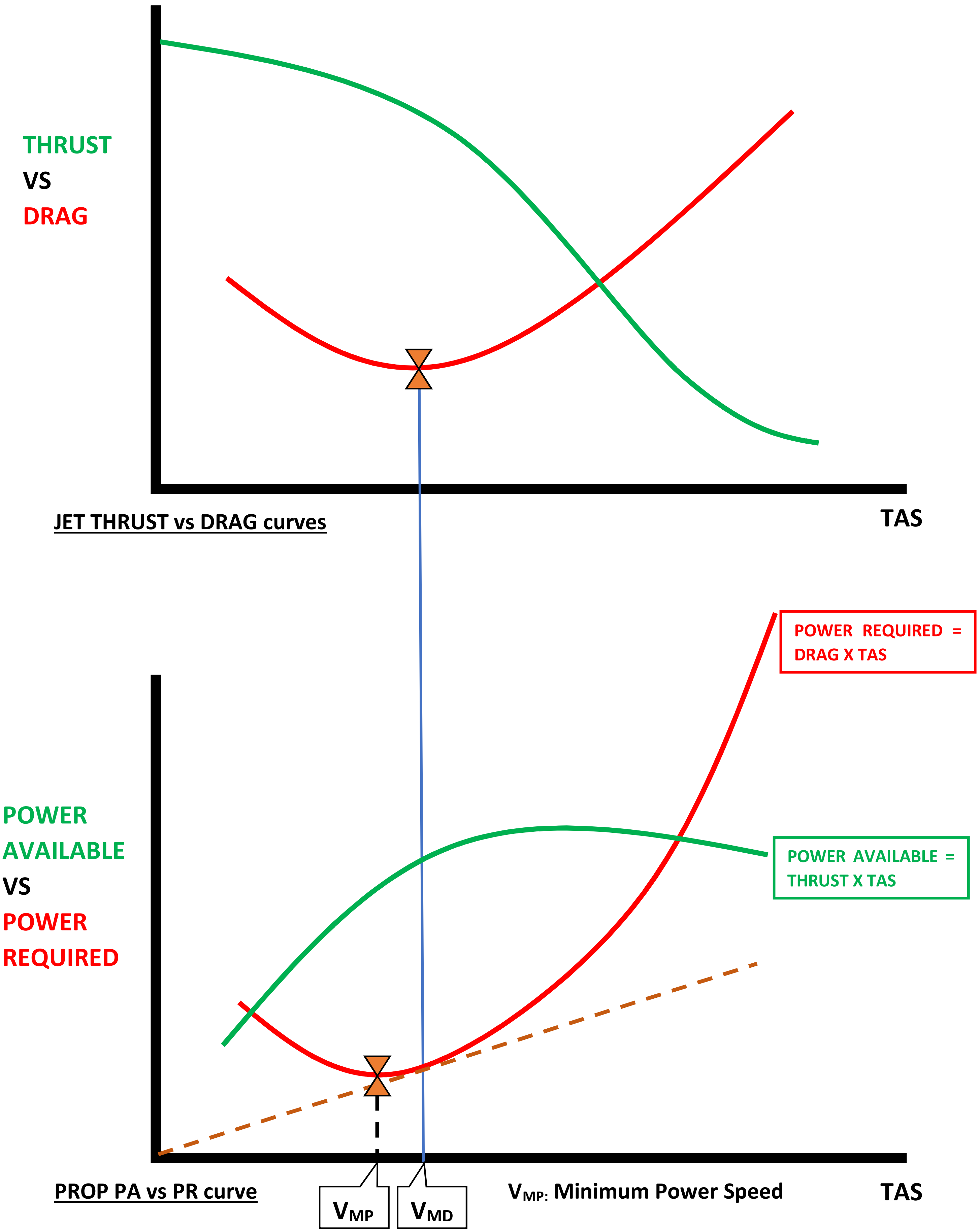
The Rate of Climb is a function of **GRADIENT** and **SPEED**

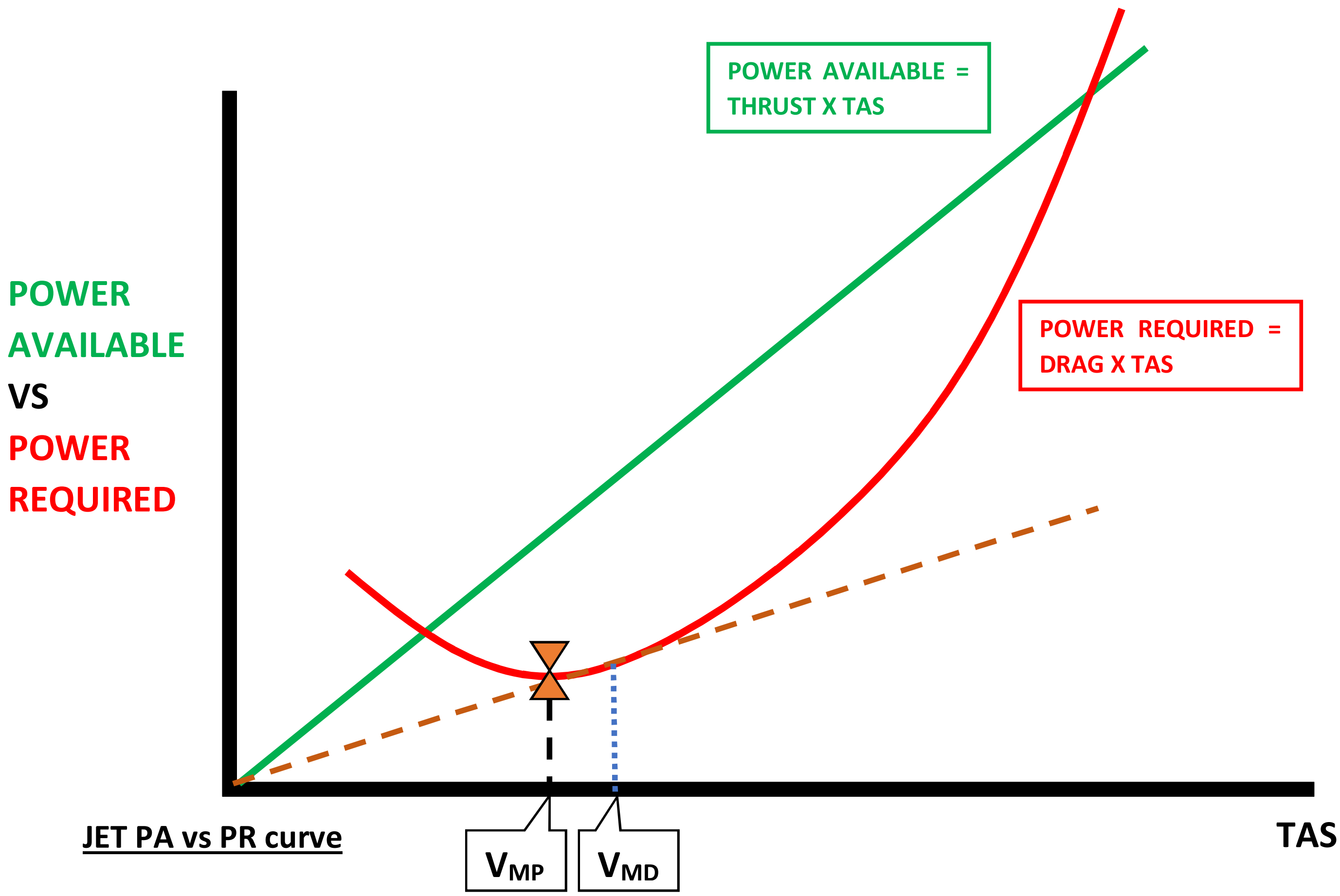
$$ROC = v\frac{Thrust - Drag}{Weight} = \frac{v.Thrust - v.Drag}{Weight}$$

$$ROC = \frac{Power\ Available - Power\ Required}{Weight}$$

$$ROC = \frac{Excess\ of\ Power\ Available}{Weight}$$


THRUST
VS
DRAG
TAS
JET THRUST vs DRAG curves
POWER AVAILABLE = THRUST X TAS
POWER REQUIRED = DRAG X TAS
POWER
AVAILABLE
VS
POWER
REQUIRED
JET PA vs PR curve
V MP
V MD
V MP : Minimum Power Speed
TAS


THRUST
VS
DRAG
JET THRUST vs DRAG curves
TAS
POWER REQUIRED = DRAG X TAS
POWER
AVAILABLE
VS
POWER
REQUIRED
POWER AVAILABLE = THRUST X TAS
PROP PA vs PR curve
VMP
VMD
VMP: Minimum Power Speed
TAS


POWER AVAILABLE = THRUST X TAS
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POWER
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VS
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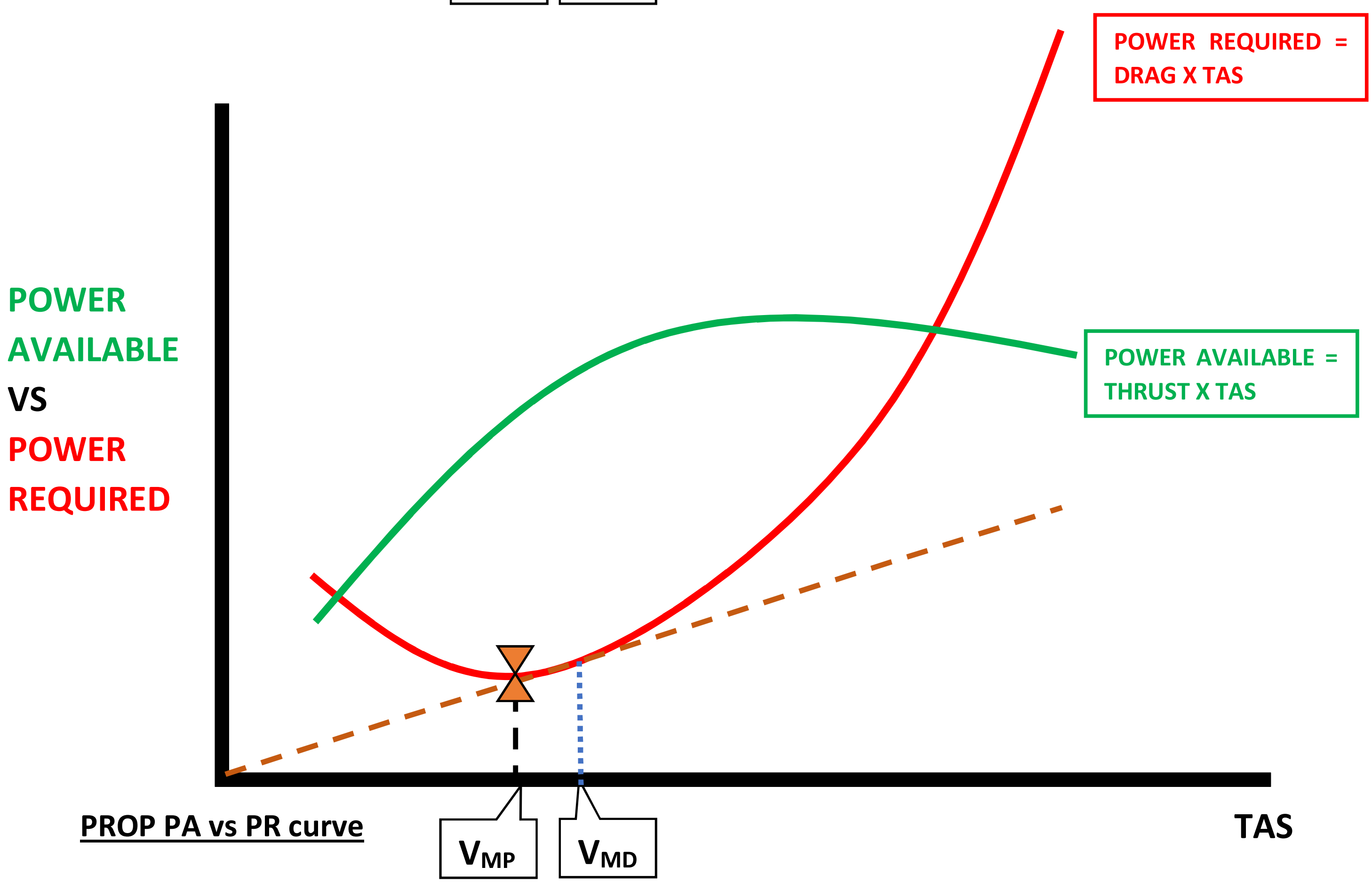
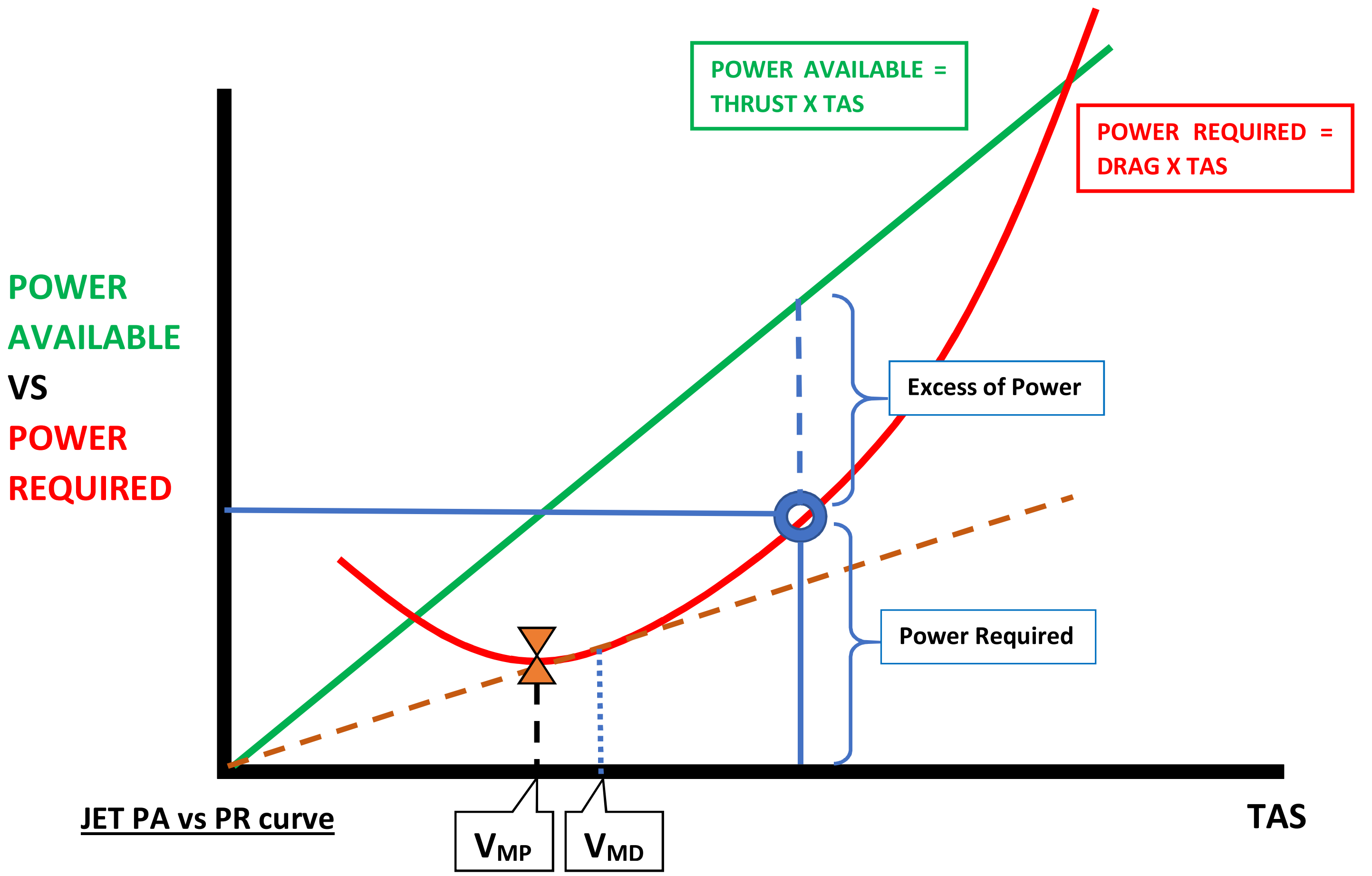
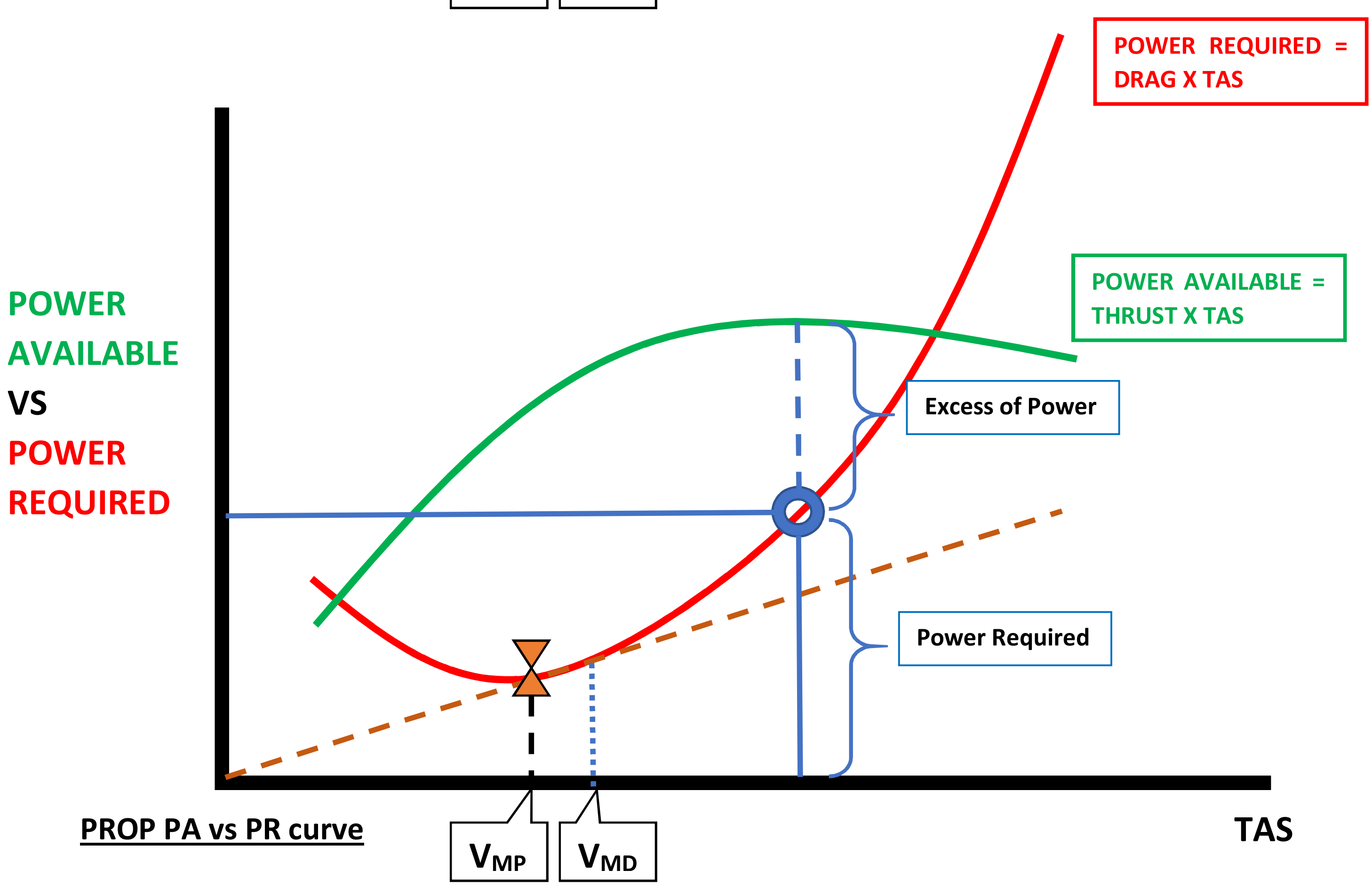
REQUIRED
JET PA vs PR curve
VMP
VMD
TAS


POWER REQUIRED = DRAG X TAS
POWER
AVAILABLE
VS
POWER
REQUIRED
POWER AVAILABLE = THRUST X TAS
PROP PA vs PR curve
VMP
VMD
TAS


POWER AVAILABLE = THRUST X TAS
POWER REQUIRED = DRAG X TAS
POWER
AVAILABLE
VS
POWER
REQUIRED
Excess of Power
Power Required
JET PA vs PR curve
V_{MP}
V_{MD}
TAS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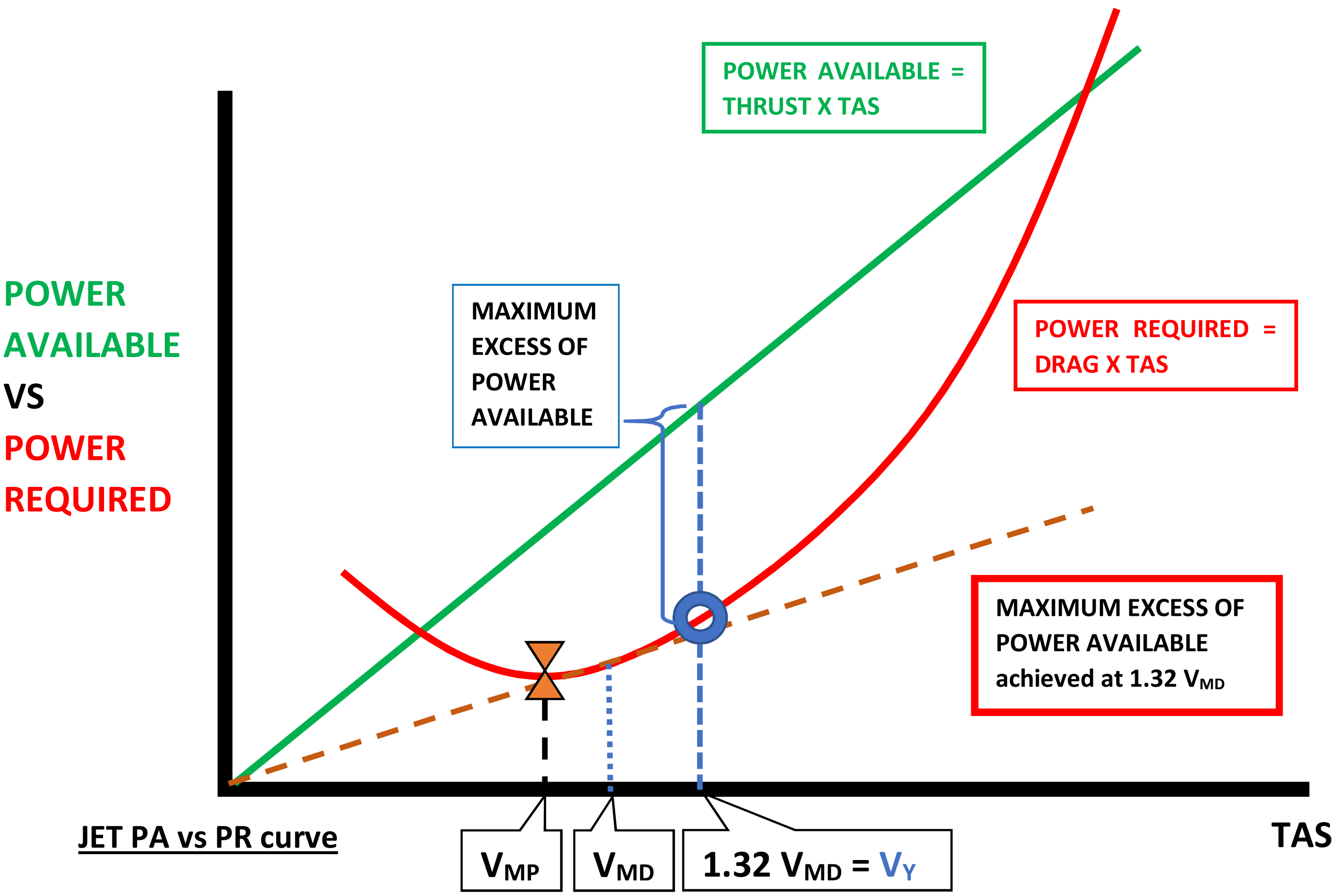
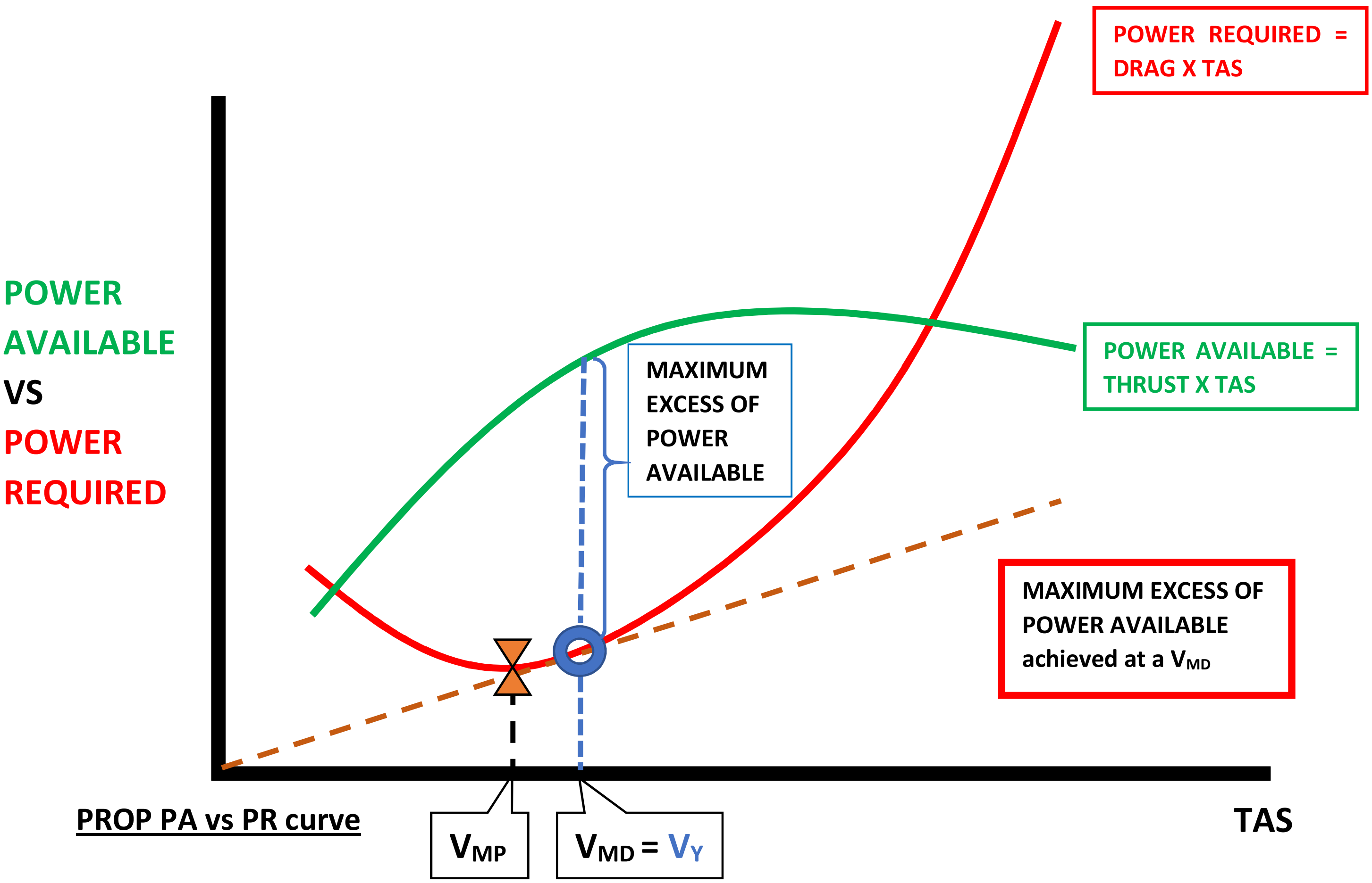
POWER AVAILABLE = THRUST X TAS
POWER
AVAILABLE
VS
POWER
REQUIRED
Excess of Power
Power Required
PROP PA vs PR curve
V_{MP}
V_{MD}
TAS



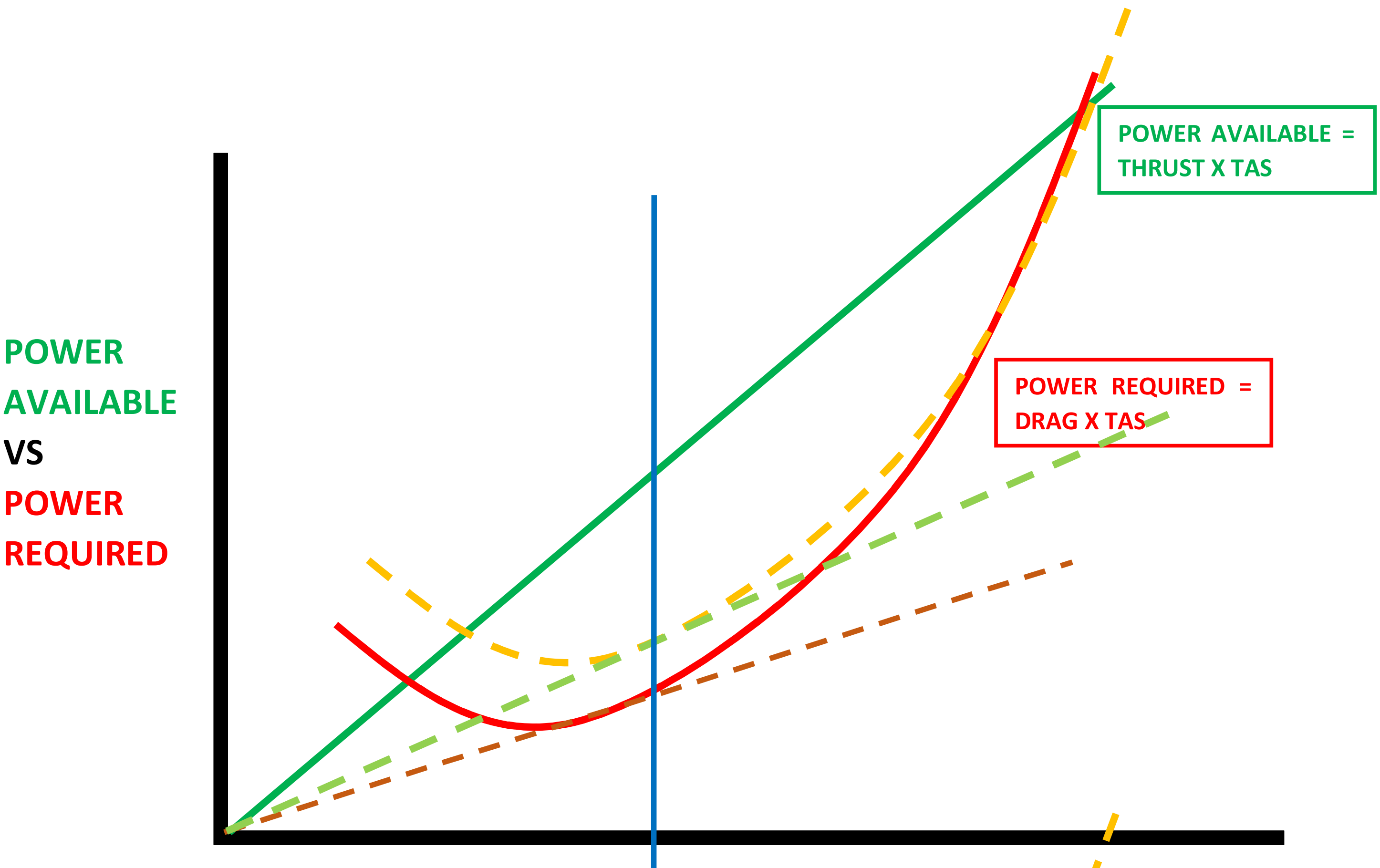
V_Y: Best rate of climb speed → For the JET engine, $V_Y = 1.32\ V_{MD}$



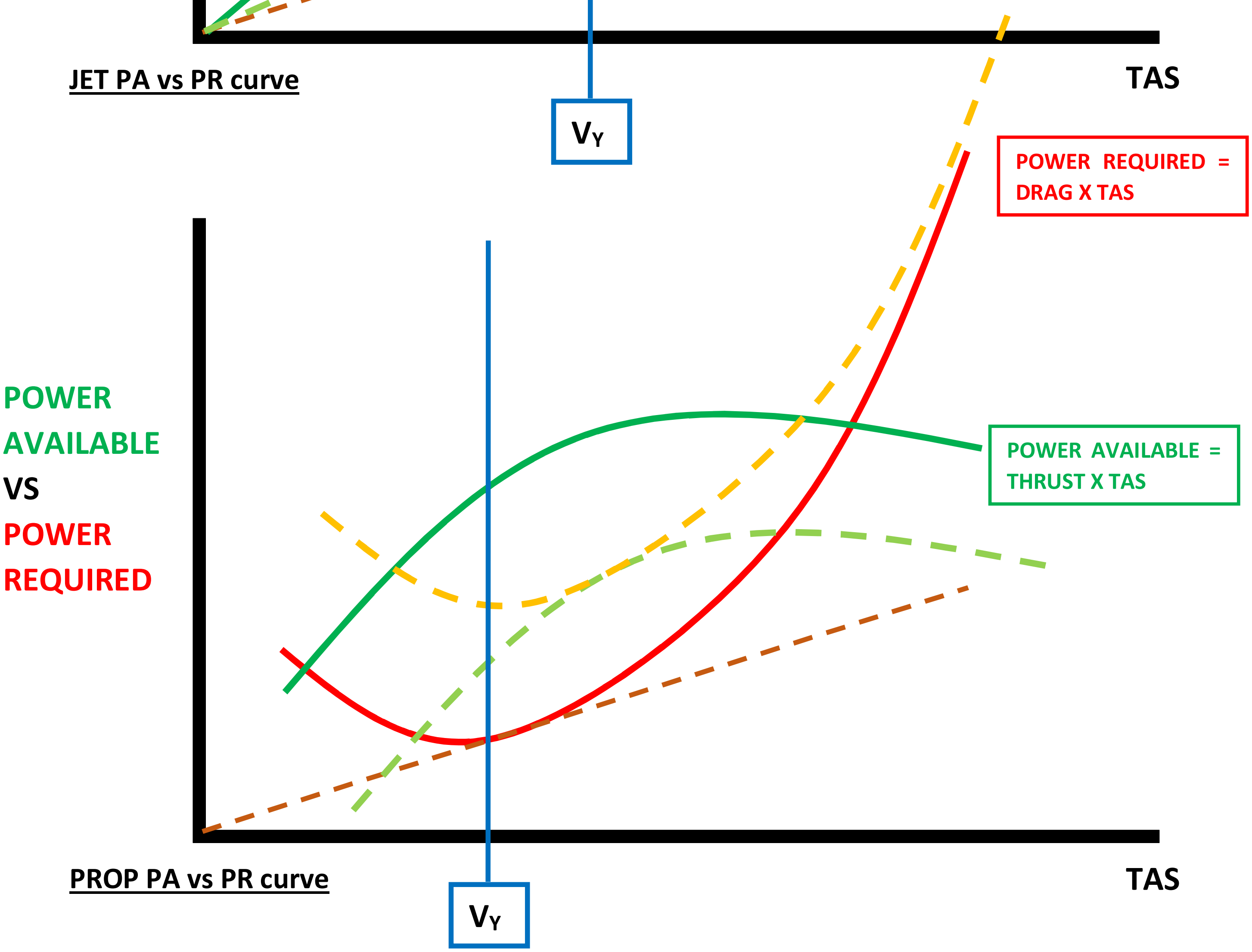
V_Y: Best rate of climb speed → For the PROP engine, $V_Y = V_{MD}$

Affecting factors

Factors	Increase ROC	Decrease ROC
Weight	Light (V_Y ↓)	Heavy (V_Y ↑)
Config (flaps)	Flaps retracted, gear up (V_Y ↑)	Flaps extended, gear down (V_Y ↓)
Density (pressure, temp)	Low pressure elev. Low temp	High pressure elev. High temp
Wind	No effect	



JET PA vs PR curve

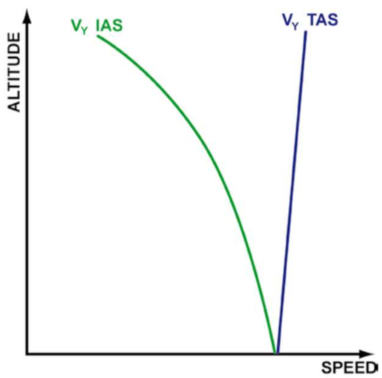


PROP PA vs PR curve

Density and ceiling

Decreased density will decrease the thrust but it will also increase the true airspeed. The overall effect is that the thrust loss is more than the TAS gain, meaning, overall, that the power available decreases.
Looking at power required, decreased density will increase the true airspeed but have no effect on the drag. Therefore the power required will increase.
Looking at the graphs for the Jet and Propeller aeroplane, the power available curve move down and right, and the power required curve move up and right. Which gives is less excess power available and this causes a reduction in the rate of climb for both aeroplane types.

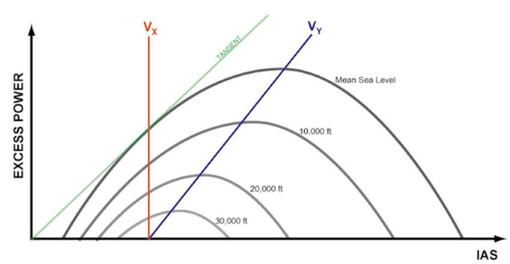
Notice from the graph that the true airspeed for V_Y increases a little with decreasing density or increasing altitude. However, the pilots when fly, use the indicated airspeeds and therefore it is important to understand what happens to the indicated airspeed of V_Y.



If the true airspeed increases only slightly with altitude, then the indicated airspeed will still fall. Therefore, although V_Y as TAS increases with decreasing density or increasing altitude, V_Y as an IAS decreases. In fact, V_Y will eventually fall to become the same value as V_X. So in summary, reduced density decreases the indicated airspeed of V_Y and decreases the rate of climb.

In relation to altitude, the higher the aeroplane flies, the excess power available diminishes and therefore the maximum achievable rate of climb will decrease.
There will be an altitude where the excess power available decreases to zero. This altitude is known as **the absolute ceiling**.

V_Y is the speed that gives the maximum excess power available and maximum achievable rate of climb. This is shown by the top of each curve. Also note that on this graph, V_X can be found at the tangent point of each curve. As altitude increases, notice that the excess power available, achievable rate of climb and the indicated airspeed for V_Y decreases. Eventually there will be an altitude where V_Y and V_X are the same and there is no more excess power and therefore, the rate of climb is zero.



At its absolute ceiling, the performance of an aeroplane is so reduced that it is unable to manoeuvre. Therefore, absolute ceiling is a rather abstract concept for a pilot. It is more useful for a pilot to know his aeroplane's service ceiling. **Service ceiling** is defined by the manufacture's and aviation authorities as the maximum altitude where the best rate of climb airspeed will still produce a positive rate of climb at a specific number of feet per minute. The recommendation is to not exceed this altitude because the performance envelope of the aeroplane is very small.

Absolute Ceiling:

The absolute ceiling is the highest altitude at which an aircraft can sustain level flight

- ➔ At the absolute ceiling, the rate of climb is **0ft/min**

Service Ceiling

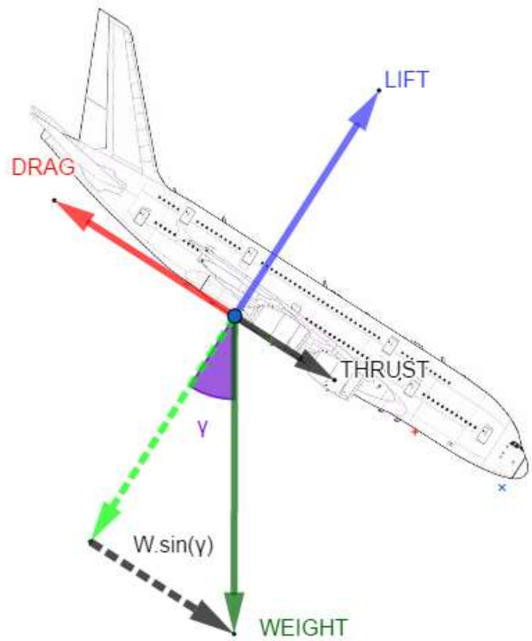
The **service ceiling** is the maximum usable altitude of an aircraft, where the rate of climb drops below a prescribed value

- ➔ A typical value might be **100ft/min**, or on the order of **500ft/min for jet aircraft**

Cruise Ceiling

- ➔ The cruise ceiling is the altitude at which the maximum climb rate is **300 ft/min**

2) Descent (DESC)

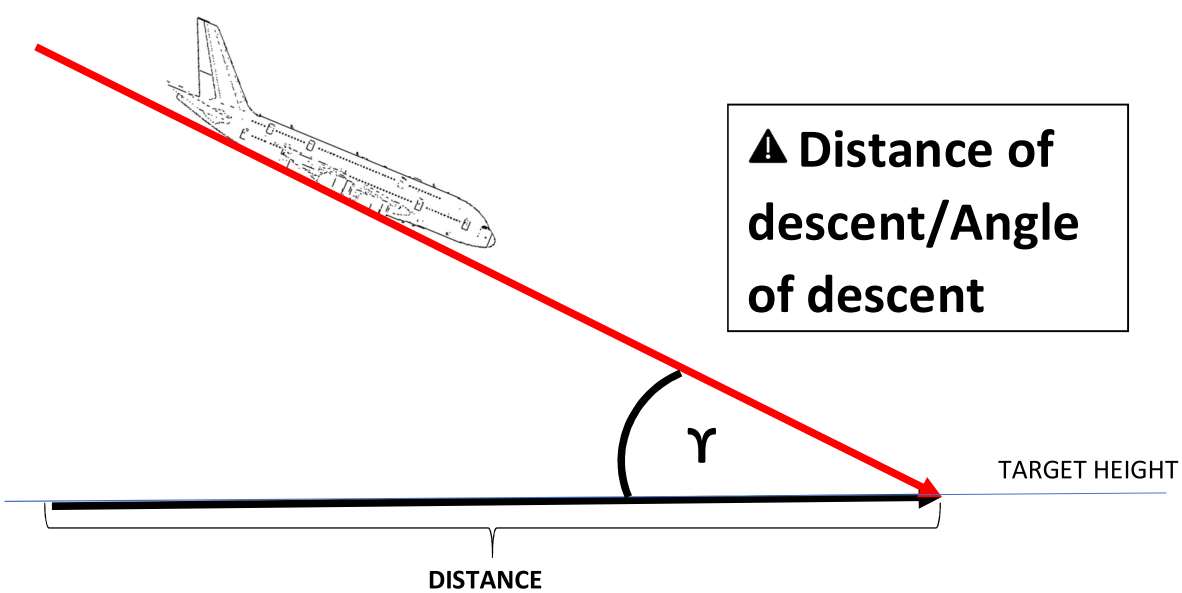


$$L < W$$
$$D > T$$
$$D = T + W.\sin \gamma$$

There are 2 ways to analyse a descent:

- Angle of descent (forward distance to reach a height)
- Rate of descent (time to reach height)

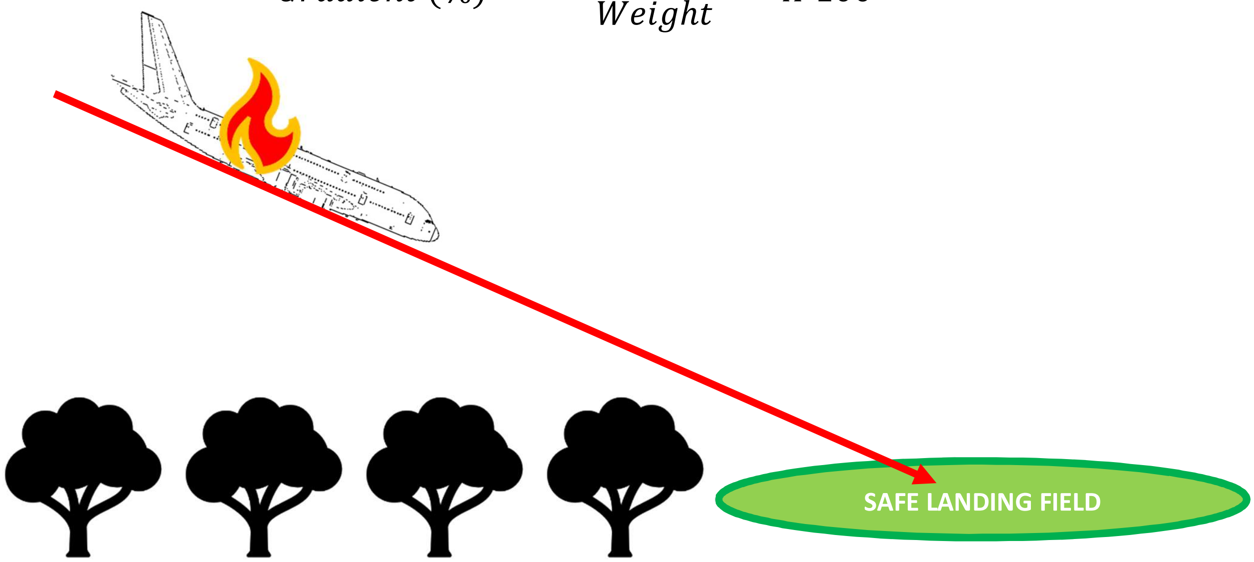
2.1) Angle of Descent



⚠ Distance of descent/Angle of descent

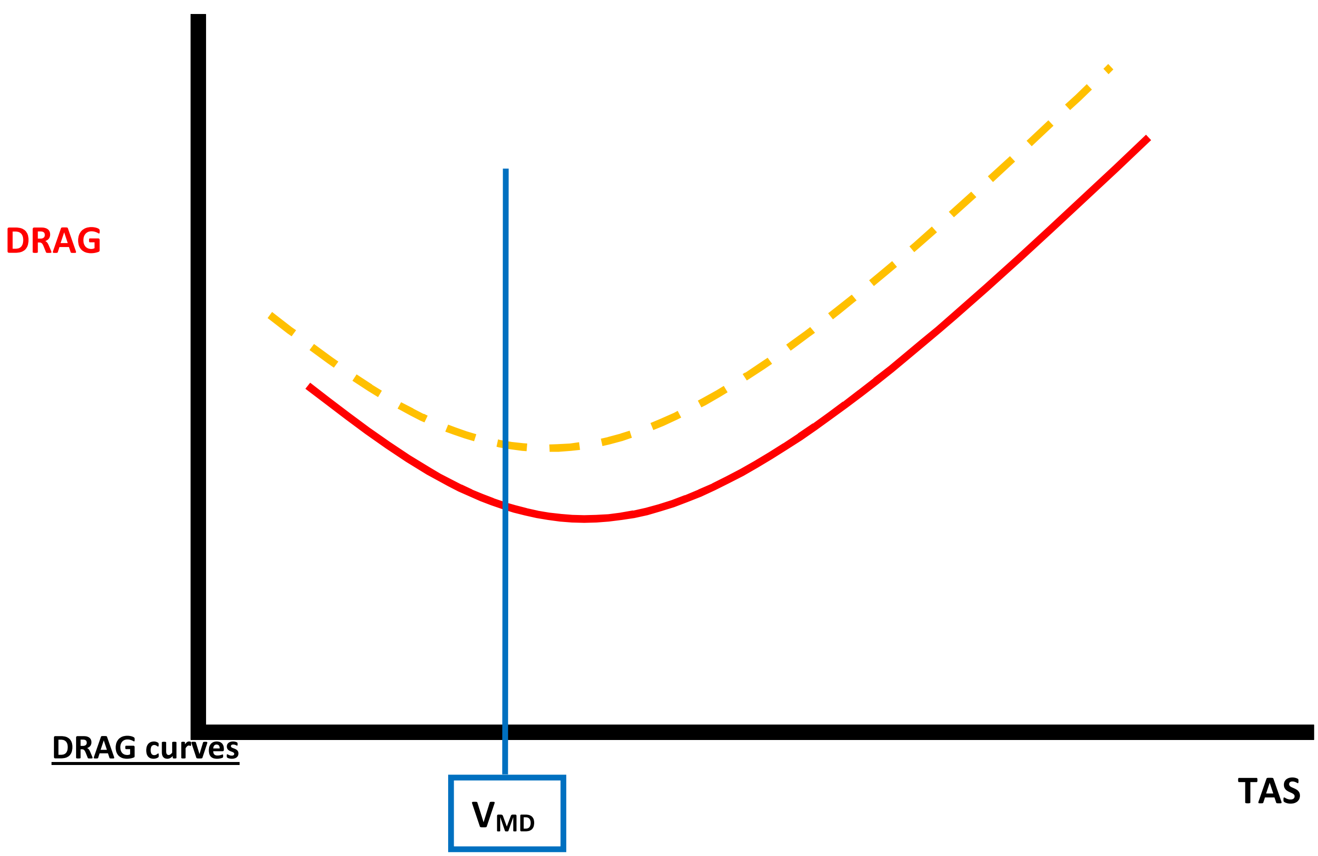
$$Gradient\ (\%) = \frac{Drag - Thrust}{Weight} X\ 100$$

$$Gradient\ (\%) = \frac{Excess\ of\ Drag}{Weight} X\ 100$$



$$Gradient\ (\%) = \frac{Drag}{Weight} X\ 100$$

Minimum angle of glide/Maximum distance of glide achieved at V_{MD}

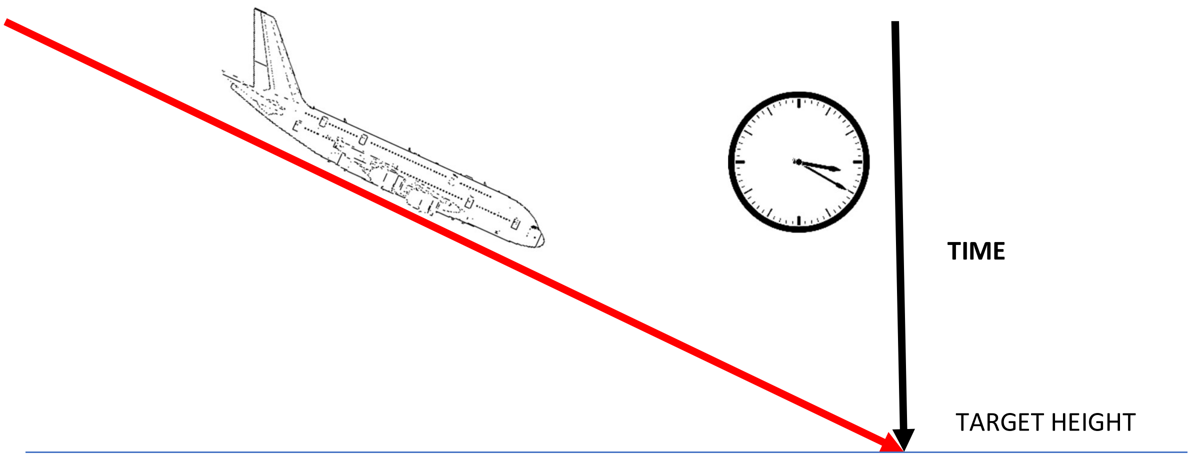


FACTORS AFFECTING

Factors	**Decrease minimum glide angle/ Increase gliding distance**	**Increase minimum glide angle/ Decrease gliding distance**
Config (flaps)	Flaps retracted, gear up (V_{MD} ↑)	Flaps extended, gear down (V_{MD} ↓)
Wind (TAS/GS x Gradient)	Tailwind	Headwind
Weight	No effect	

2.2) Rate of Descent

Vertical speed (usually expressed in ft/min)

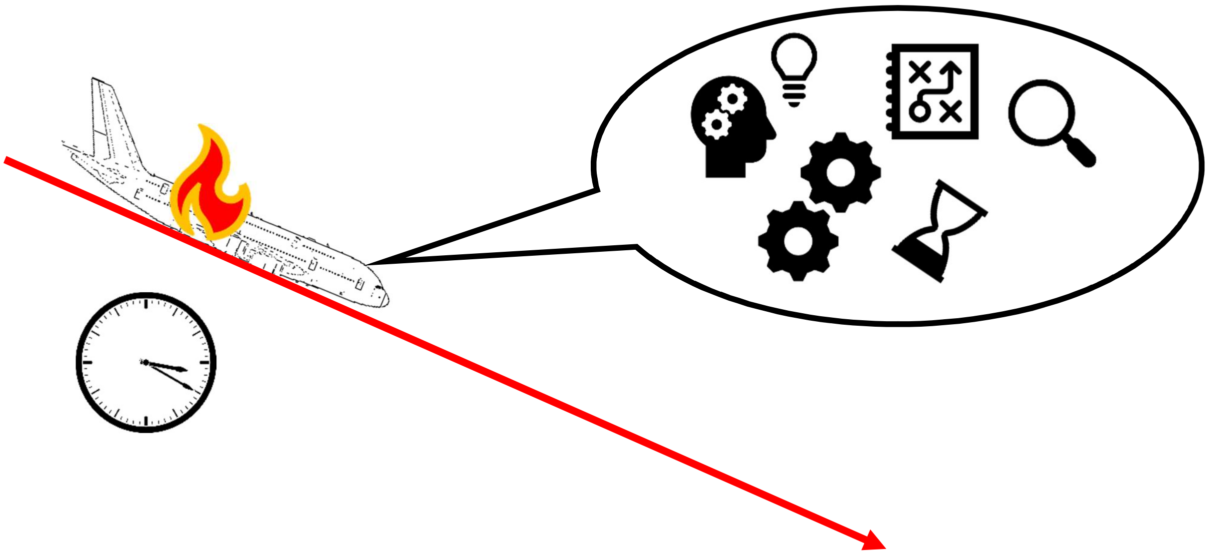


The Rate of Descent is a function of **GRADIENT** and **SPEED**

$$ROD = v\frac{Drag - Thrust}{Weight} = \frac{v.Drag - v.Thrust}{Weight}$$

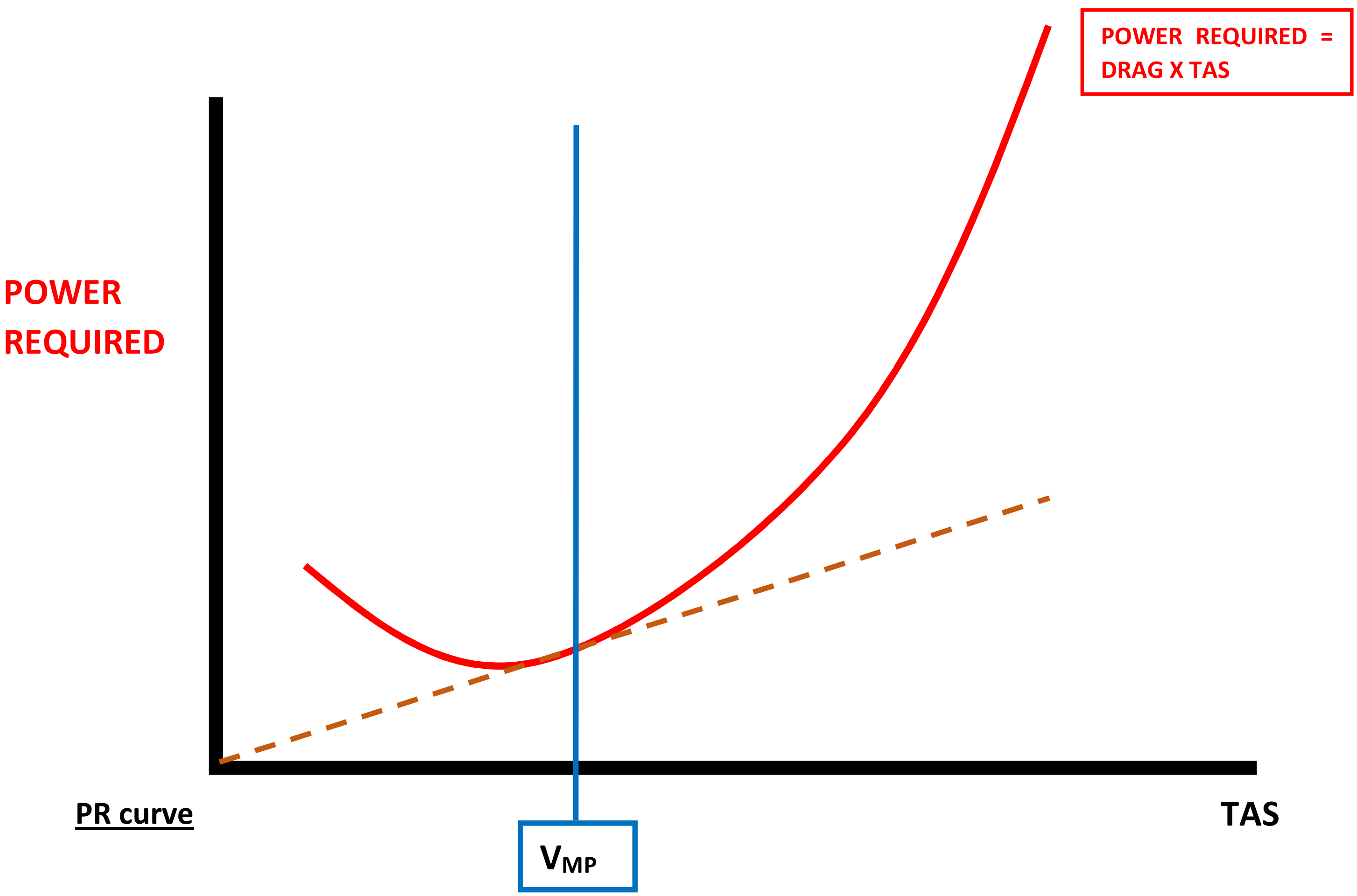
$$ROD = \frac{Power\ Required - Power\ Available}{Weight}$$

$$ROD = \frac{Excess\ of\ Power\ Required}{Weight}$$



$$ROD = \frac{Power\ Required}{Weight}$$

Minimum Rate of Descent (ROD) achieved at V_{MP}



FACTORS AFFECTING

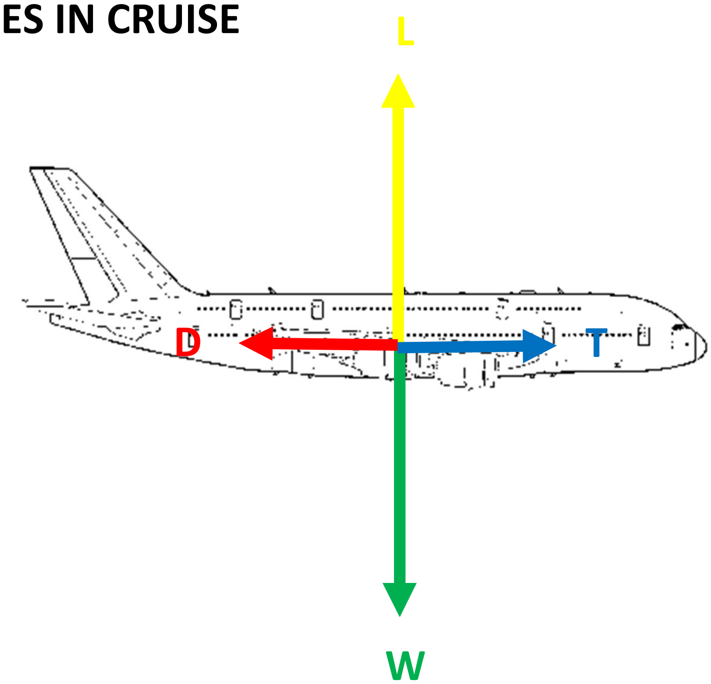
Factors	Decrease minimum ROD	Increase minimum ROD
Weight	Light (V_{MP} $\downarrow$)	Heavy (V_{MP} $\uparrow$)
Config (flaps)	Flaps retracted, gear up (V_{MP} $\uparrow$)	Flaps extended, gear down (V_{MP} $\downarrow$)
Wind	No effect	

SPEEDS SUMMARY

Speed	JET	PROP
Best angle of climb (V_X)	V_{MD}	$V < V_{MD}$
Best rate of climb (V_Y)	1.32 V_{MD}	V_{MD}
Best glide	V_{MD}	
Minimum ROD	V_{MP}	

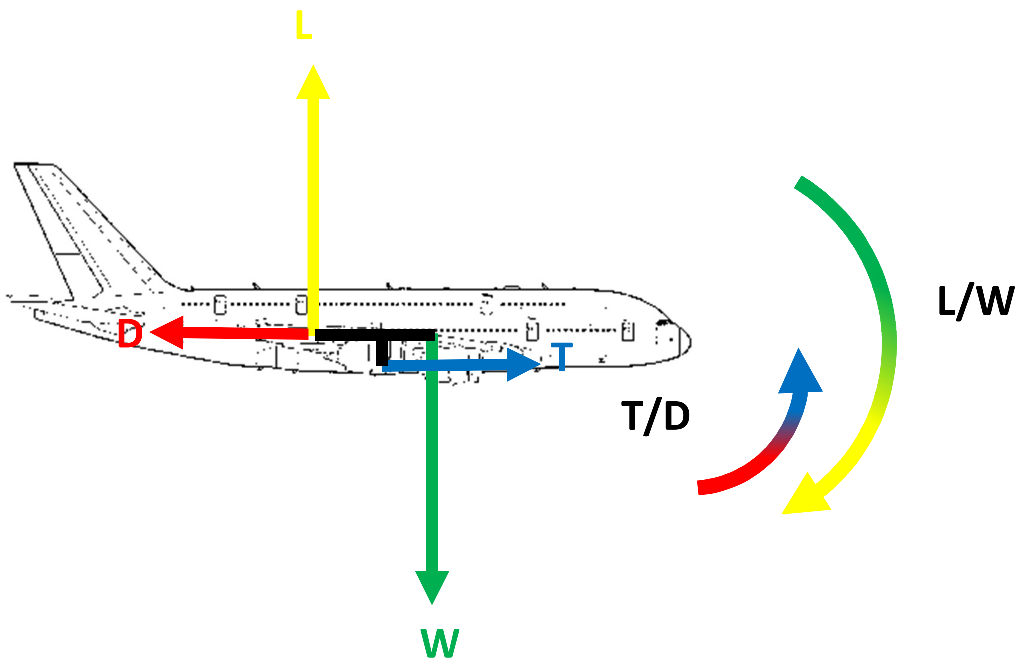
C) CRUISE

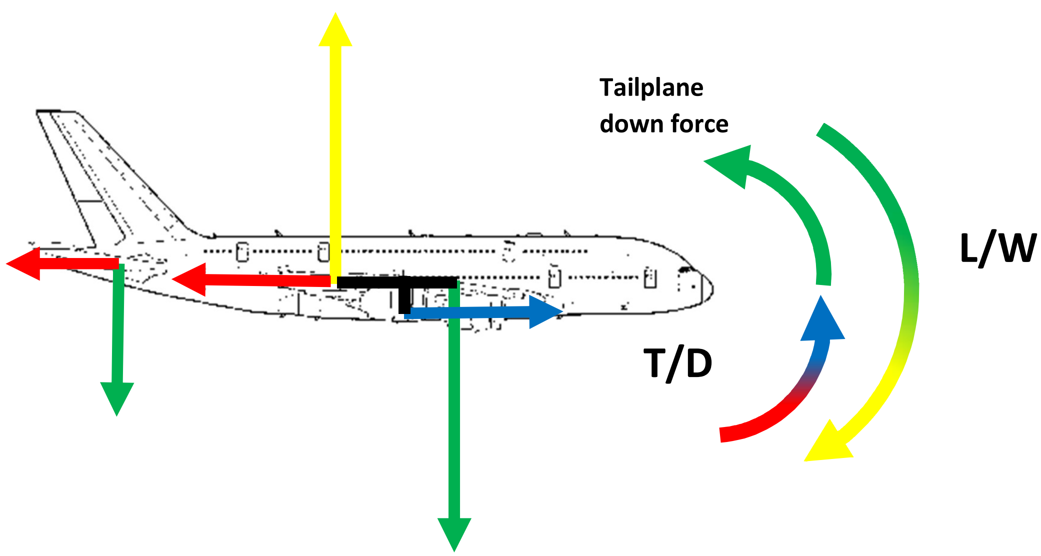
1) FORCES IN CRUISE



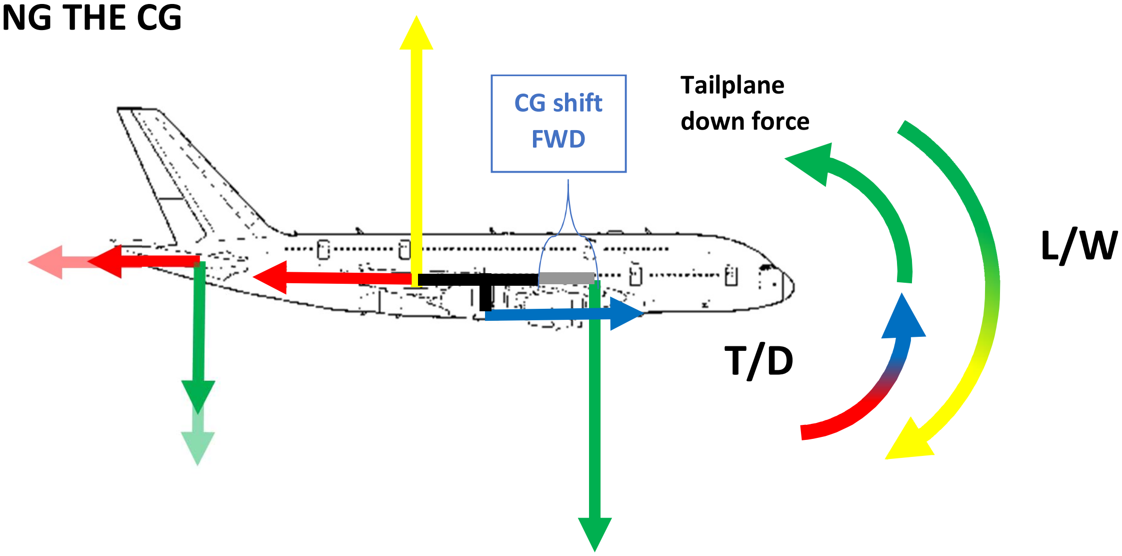
$$L = W$$

$$T = D$$


L
D
T
W
T/D
L/W


Tailplane
down force
T/D
L/W

SHIFTING THE CG



	AFT CG	FWD CG
Effective aircraft weight	↓	↑
Total Drag	↓	↑
V_S	↓	↑
Endurance	↑	↓
Range	↑	↓
Longitudinal static stability	↓	↑
Longitudinal static manoeuvrability	↑	↓

2) AIRCRAFT SPEEDS

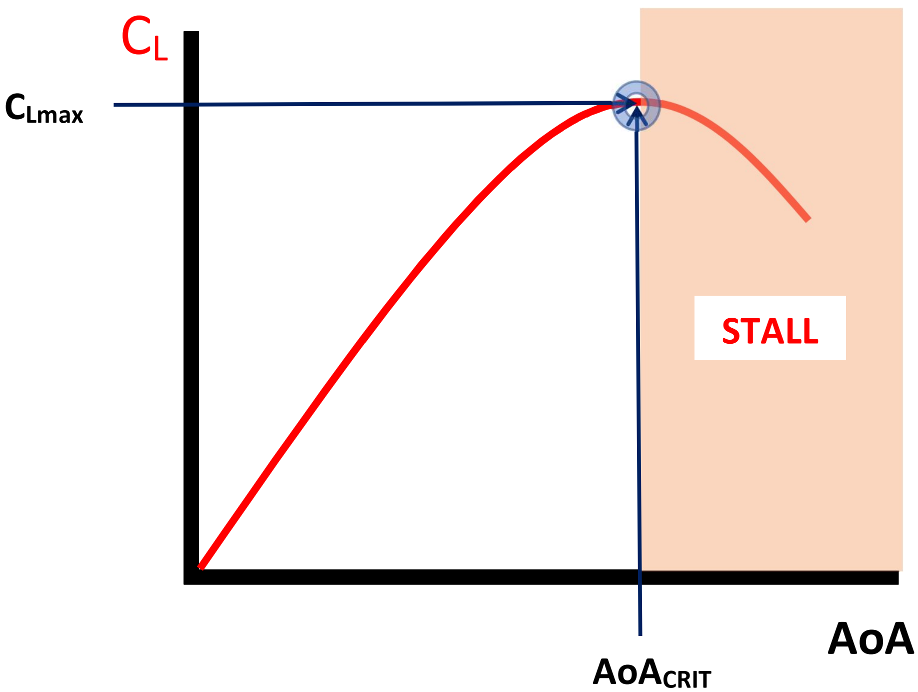
1) Minimum Speed

Minimum speed is the speed that allow the aircraft to maintain the required LIFT to act against the weight at C_{Lmax}

$$W = L$$

$$m.g = ½.\rho.V^2.S.C_L$$

$$m.g = ½.\rho.{\color{red}V_{min}}^2.S.{\color{red}C_{Lmax}}$$



STALL

<u>Weight factor</u>

$$m.g = ½.\rho.V_{min}^2.S.C_{Lmax}$$

If the initial mass (m_{OLD}) changes by *n*, the new mass (m_{NEW}) is:
$m_{NEW} = n . m_{OLD}$

At m_{OLD}, the minimum speed was V_{minOLD}, and at At m_{NEW}, the minimum speed was V_{minNEW}

$$\begin{cases} m_{OLD}.g = ½.\rho.V_{minOLD}{}^2.S.C_{Lmax} \\ m_{NEW}.g = ½.\rho.V_{minNEW}{}^2.S.C_{Lmax} \end{cases}$$

$$\begin{cases} n.m_{OLD}.g = n.½.\rho.V_{minOLD}{}^2.S.C_{Lmax} \\ m_{NEW}.g = ½.\rho.V_{minNEW}{}^2.S.C_{Lmax} \end{cases}$$

$$\begin{cases} m_{NEW}.g = n.m_{OLD}.g \\ ½.\rho.V_{minNEW}{}^2.S.C_{Lmax} = n.½.\rho.V_{minOLD}{}^2.S.C_{Lmax} \end{cases}$$

$$\cancel{½.\rho.}V_{minNEW}{}^2\cancel{.S.C_{Lmax}} = n\cancel{.½.\rho.}V_{minOLD}{}^2\cancel{.S.C_{Lmax}}$$

$$V_{minNEW}{}^2 = n.V_{minOLD}{}^2$$

$$\boxed{V_{minNEW} = V_{minOLD}\,.\sqrt{n}} \Leftrightarrow \boxed{V_{Snew} = V_{Sold}\,.\sqrt{n}}$$

$$\boxed{V_{Snew} = V_{Sold}\,.\sqrt{\frac{new\ mass}{old\ mass}}}$$

<u>Load factor</u>

$$m.g = ½.\rho.V_{min}{}^2.S.C_{Lmax}$$

If the initial Load Factor (1g) changes by *n*, the Load Factor (ng) is:

ng = n . 1g

At 1g, the minimum speed was V_{min1G}, and at At ng, the minimum speed was $V_{min\ nG}$

$$\begin{cases} m.1g = ½.\rho.V_{min1G}{}^{2}.S.C_{Lmax} \\ m.ng = ½.\rho.V_{min\,nG}{}^{2}.S.C_{Lmax} \end{cases}$$

$$\begin{cases} m.n1g = n.½.\rho.V_{min1G}{}^{2}.S.C_{Lmax} \\ m.ng = ½.\rho.V_{min\,nG}{}^{2}.S.C_{Lmax} \end{cases}$$

$$\begin{cases} m.ng = m.n1g \\ ½.\rho.V_{min\,nG}{}^{2}.S.C_{Lmax} = n.½.\rho.V_{min1G}{}^{2}.S.C_{Lmax} \end{cases}$$

$$\cancel{½.\rho.}V_{min\,nG}{}^{2}\cancel{.S.C_{Lmax}} = n\cancel{.½.\rho.}V_{min1G}{}^{2}\cancel{.S.C_{Lmax}}$$

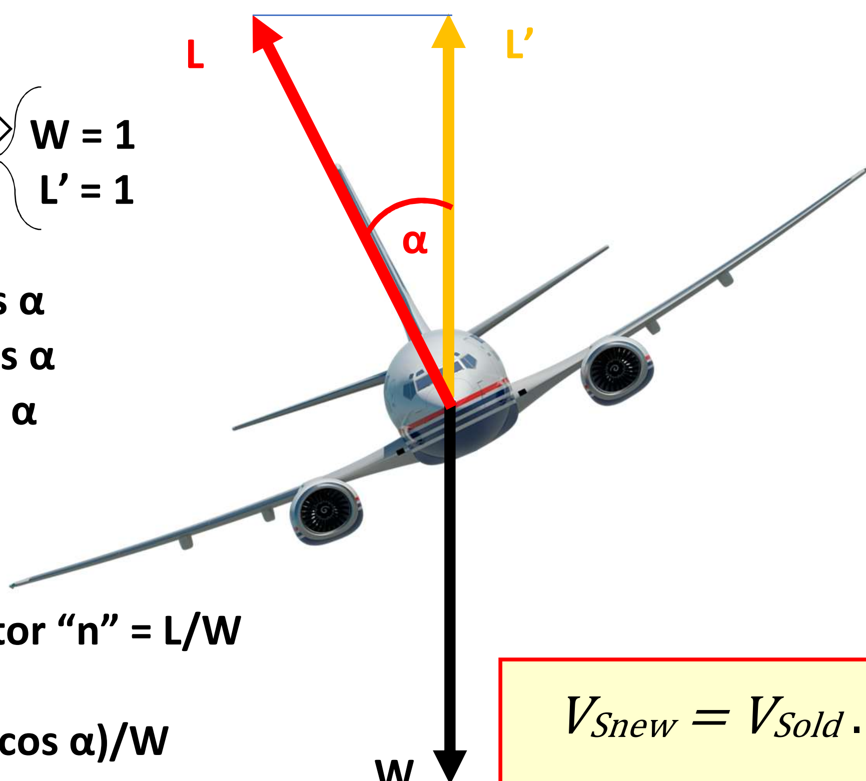
$$V_{min\,nG}{}^{2} = n.V_{min1G}{}^{2}$$

$$\boxed{V_{min\,nG} = V_{min1G}.\sqrt{n}} \Leftrightarrow \boxed{V_{Snew} = V_{Sold}.\sqrt{n}}$$

In turn

W = L’ ⇔ { W = 1, L’ = 1 }

L = L’/cos α
L = W/cos α
L = 1/cos α

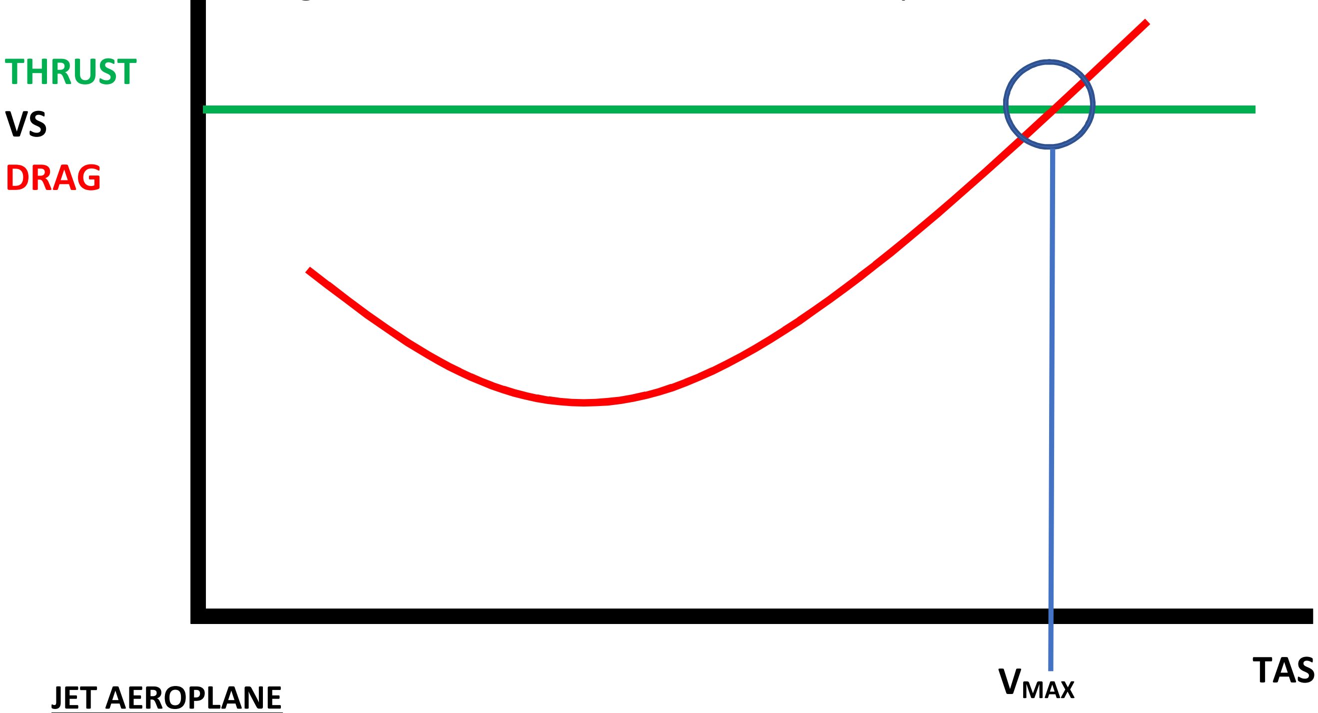


Load factor “n” = L/W
In turn,
“n” = (1/cos α)/W
“n” = 1/cos α

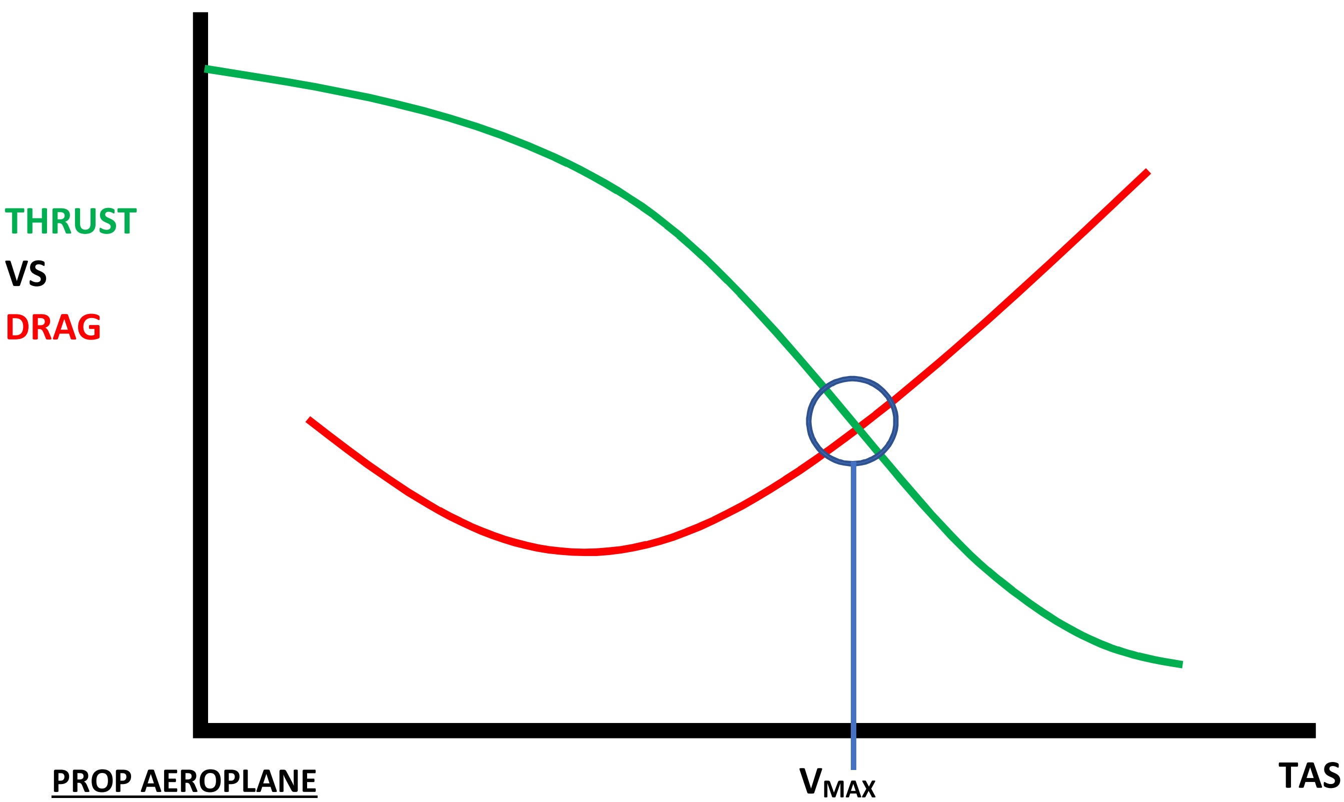
$$\boxed{V_{Snew} = V_{Sold}.\sqrt{1/\cos\alpha}}$$

2) Maximum Speed

When the aircraft is unable to provide further THRUST to act again t its total DRAG, the Maximum Speed is reached

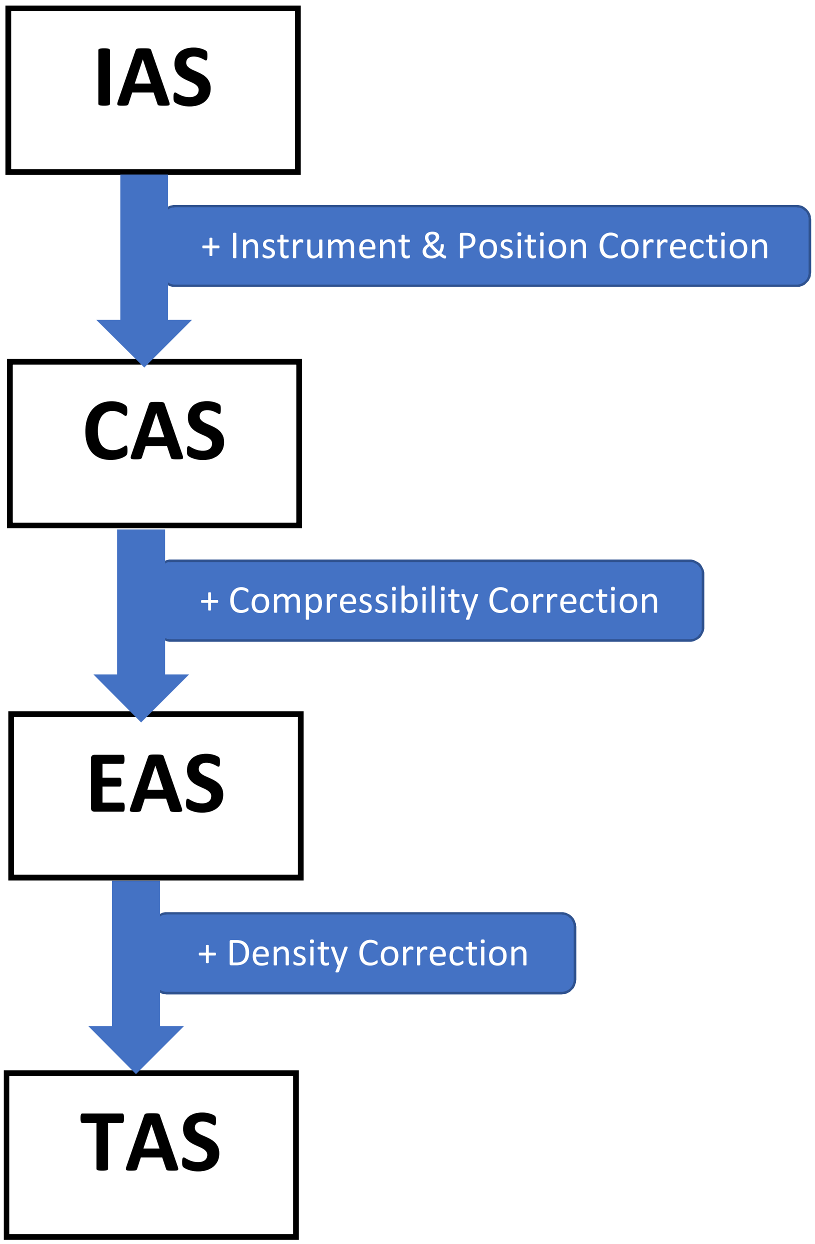


JET AEROPLANE



PROP AEROPLANE

3) Different speeds



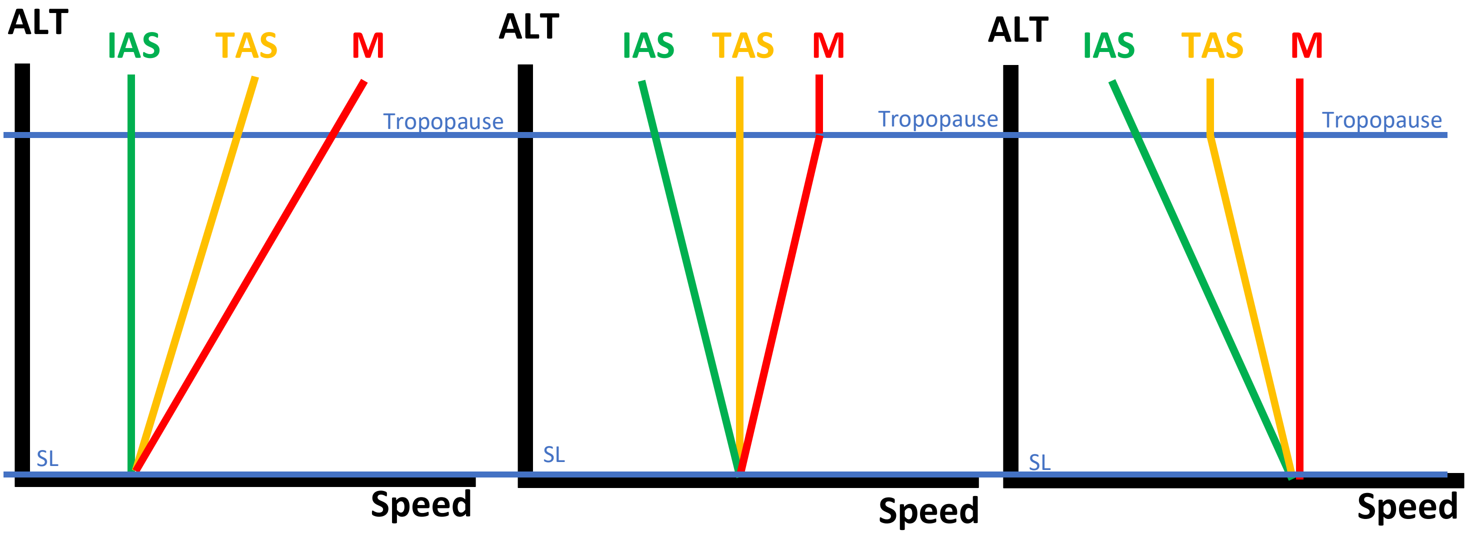
Mach Number

Ratio between the TAS and the Local Speed of Sound (LSS)

$$Mach = \frac{TAS}{LSS}$$

$$LSS\ (kt) = 38{,}95\sqrt{T°C + 273}$$

$$Mach = \frac{TAS}{38{,}95\sqrt{T°C + 273}}$$



In climb, monitor M_{MO}
In descent, monitor V_{NE}

3) ENDURANCE

The endurance of an aeroplane is the time it can remain airborne on a given quantity of fuel or, put another way, endurance can be expressed as fuel used over a given airborne time.

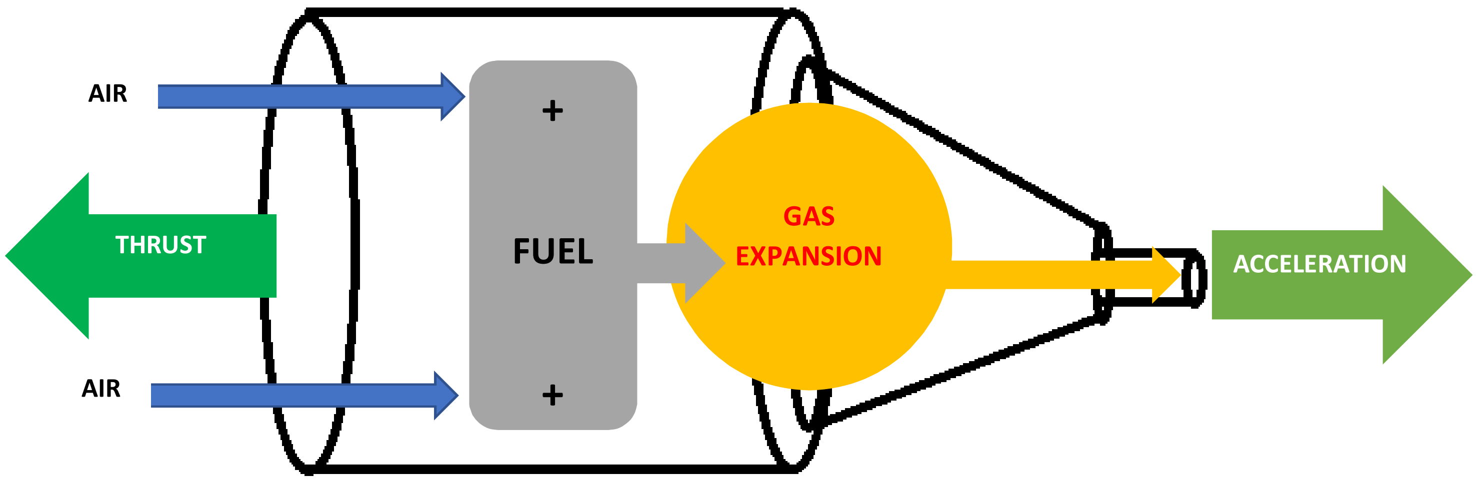
$$Endurance = \frac{Time\ (hrs)}{Fuel\ (kg)}$$

To use this formula, an arrangement must be made

$$Specific\ Endurance\ (hr/kg) = \frac{1}{Fuel\ Flow}$$

➔ Maximum endurance achieved at minimum Fuel Flow

JET AEROPLANE ENDURANCE



The FUEL provides the THRUST → Fuel Flow per unit of Thrust

$$Fuel\ Flow = Fuel\ Flow\ per\ unit\ of\ Thrust\ X\ Total\ Thrust$$

Fuel Flow per unit of Thrust is also called **Specific Fuel Consumption (SFC)**

$$Fuel\ Flow = SFC\ X\ Total\ Thrust$$

Since the THRUST is provided to act against the DRAG, therefore the Fuel Flow will depend on the Total Drag.

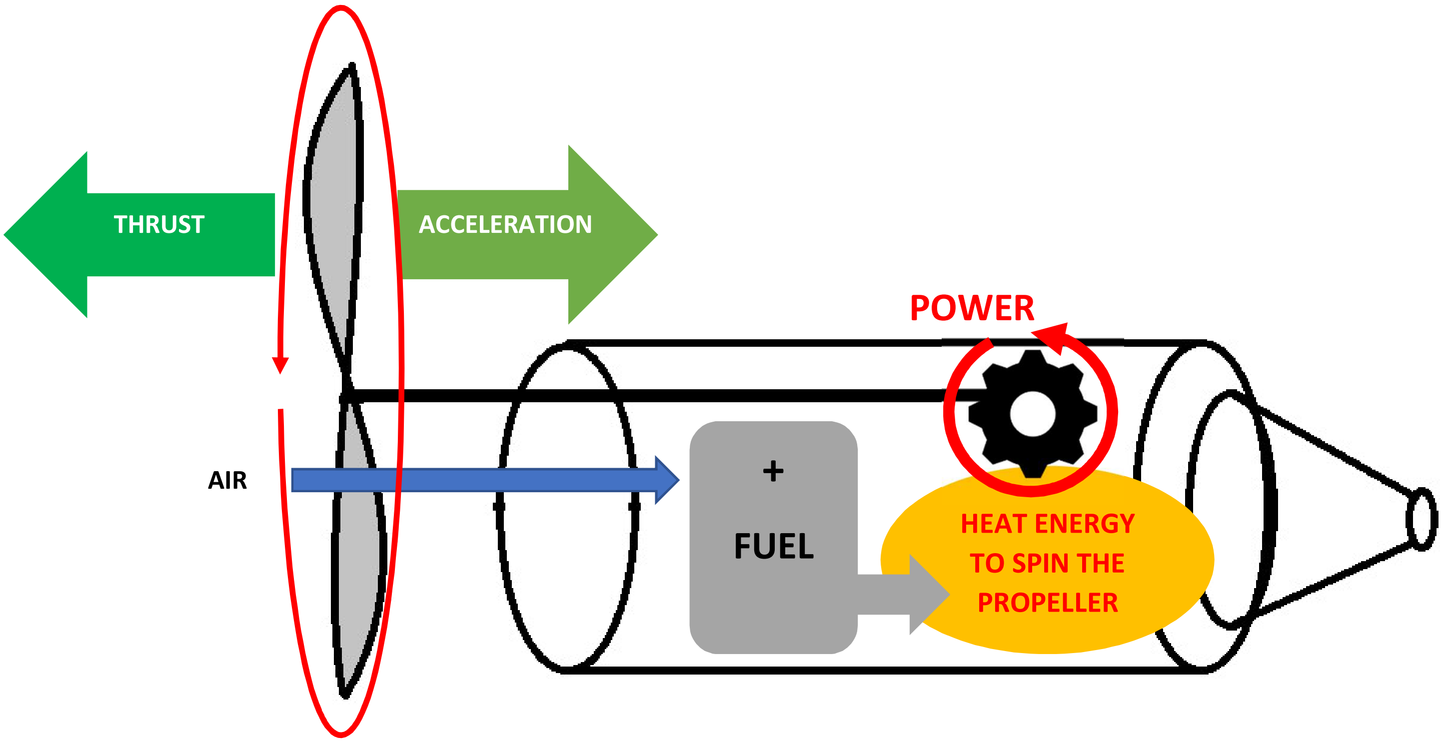
$$Fuel\ Flow = SFC\ X\ Total\ Drag$$

So now we can clearly see that the minimum Fuel Flow will be obtained by creating the minimum Total Drag. Therefore, when we refer to the DRAG curve, we can see that the minimum Total Drag is created at V_{MD}. When flying at V_{MD}, the minimum Fuel Flow is supplied and so, the maximum endurance is achieved.

SUMMARY

For a **JET AEROPLANE**, the **MAXIMUM ENDURANCE** is achieved at $\mathbf{V_{MD}}$

PROP AEROPLANE ENDURANCE



The FUEL provides the POWER → Fuel Flow per unit of Power

$$Fuel\ Flow = Fuel\ Flow\ per\ unit\ of\ Power\ X\ Total\ Power$$

Fuel Flow per unit of Power is also called **Specific Fuel Consumption (SFC)**

$$Fuel\ Flow = SFC\ X\ Total\ Power$$

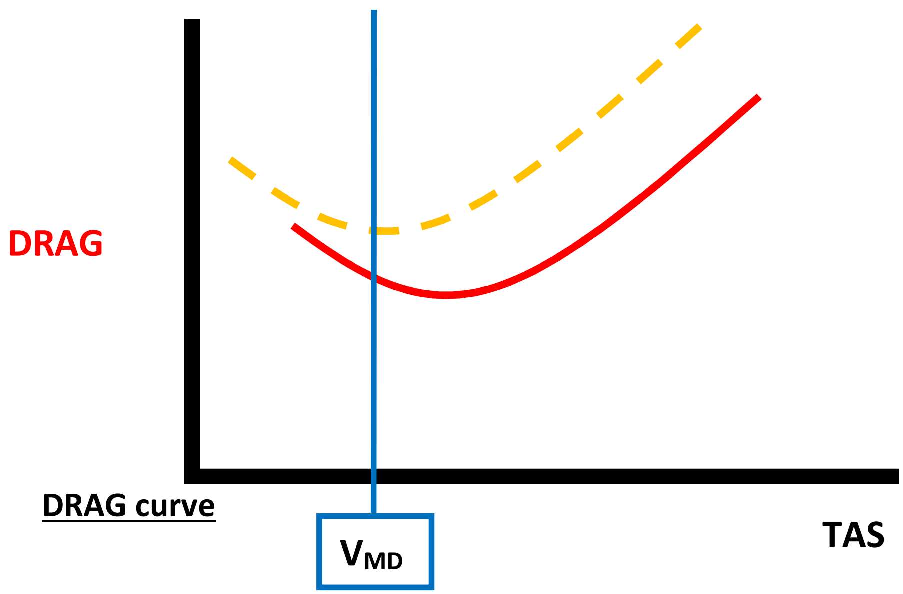
So now we can clearly see that the minimum Fuel Flow will be obtained by creating the minimum Total Power. Therefore, when we refer to the Power Required curve, we can see that the minimum Power Required is obtained at V_{MP}. When flying at V_{MP}, the minimum Fuel Flow is supplied and so, the maximum endurance is achieved.

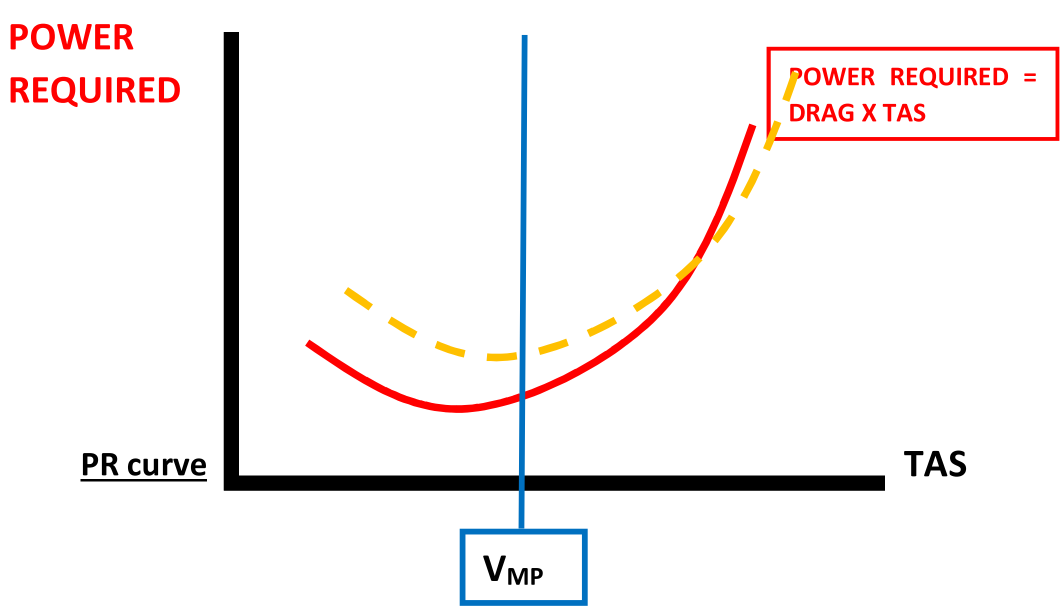
SUMMARY

For a **PROP AEROPLANE**, the **MAXIMUM ENDURANCE** is achieved at $\mathbf{V_{MP}}$

FACTORS AFFECTING

Factors	Increase best ENDURANCE	Decrease best ENDURANCE
Weight	Light, AFT CG (V_{MD} ↓) (V_{MP} ↓)	Heavy, FWD CG (V_{MP} ↑) (V_{MD} ↑)
Config (flaps)	Flaps retracted, gear up (V_{MP} ↑) (V_{MD} ↑)	Flaps extended, gear down (V_{MP} ↓) (V_{MD} ↓)
Altitude	**BEST ALT** Jet: Tropopause / Prop: 10000 ft / Piston Engine: Sea Level	
Wind	No effect since the wind won't affect the fuel flow	





4) RANGE

Maximum range can be defined as being the maximum distance an aeroplane can fly for a given fuel quantity consumed or to put it another way, the minimum fuel used by an aeroplane over a given distance.

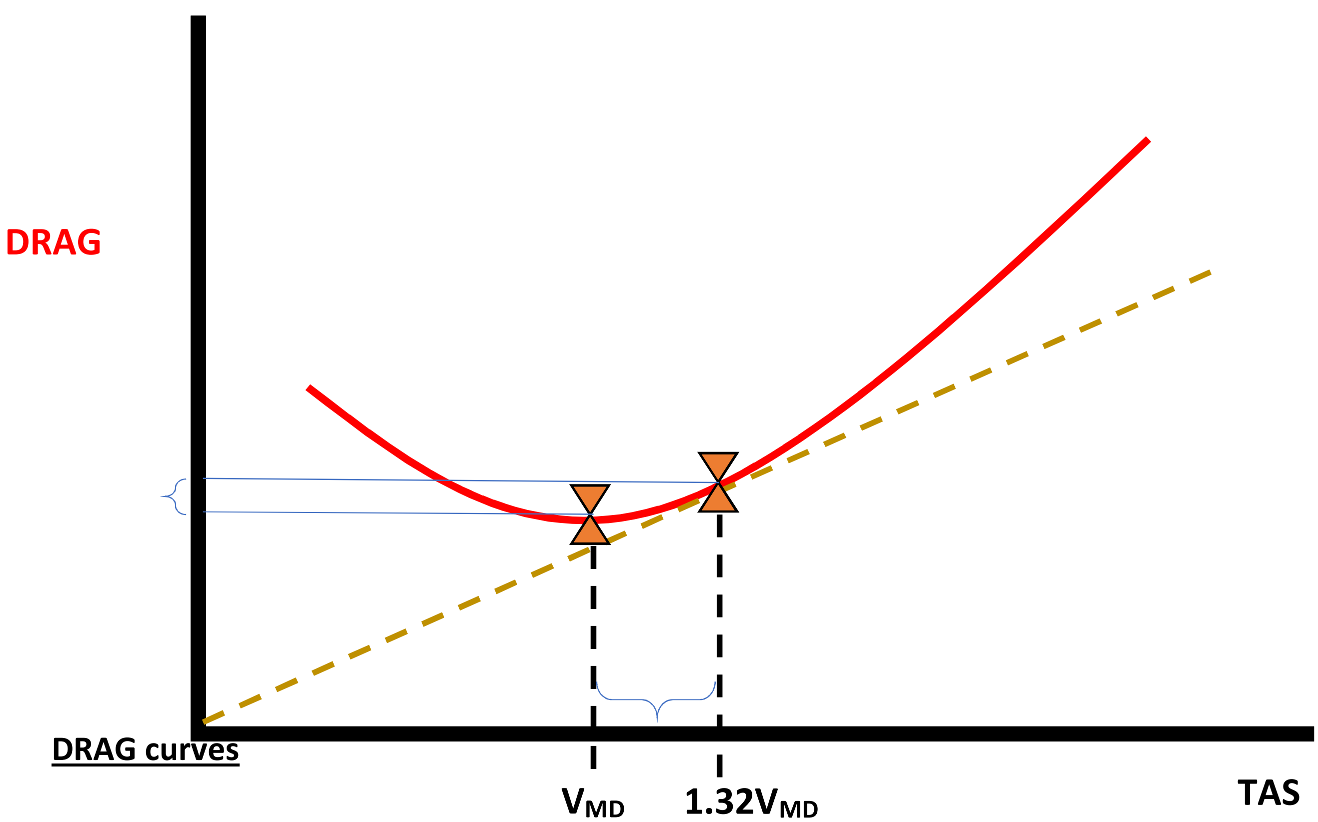
$$Range = \frac{Distance\ (nm)}{Fuel\ (kg)}$$

To use this formula, an arrangement must be made

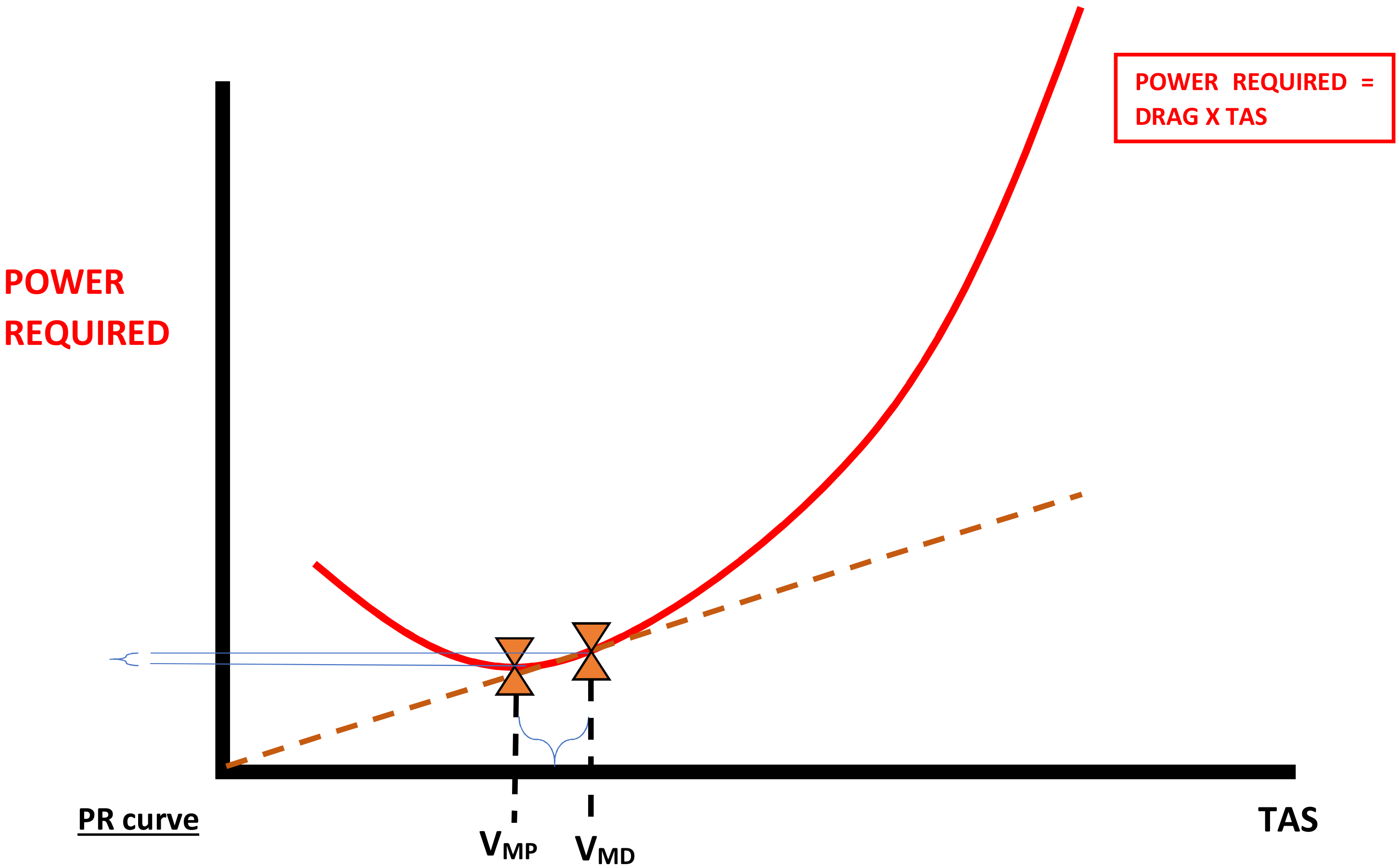
$$Specific\ Range\ (SR) = \frac{TAS\ (nm/hrs)}{Fuel\ Flow\ (kg/hrs)}$$

JET aeroplane $$Specific\ Range\ (SR) = \frac{TAS}{SFC\ X\ Total\ Drag}$$

PROP aeroplane $$Specific\ Range\ (SR) = \frac{TAS}{SFC\ X\ Total\ Power}$$



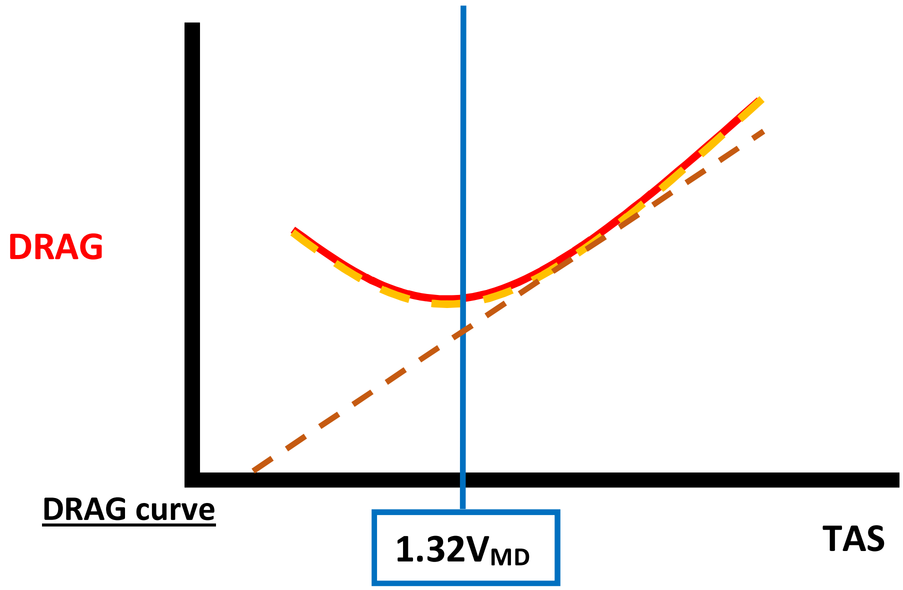
➔ **JET AEROPLANE**, the **MAXIMUM RANGE** is achieved at $\mathbf{1.32V_{MD}}$

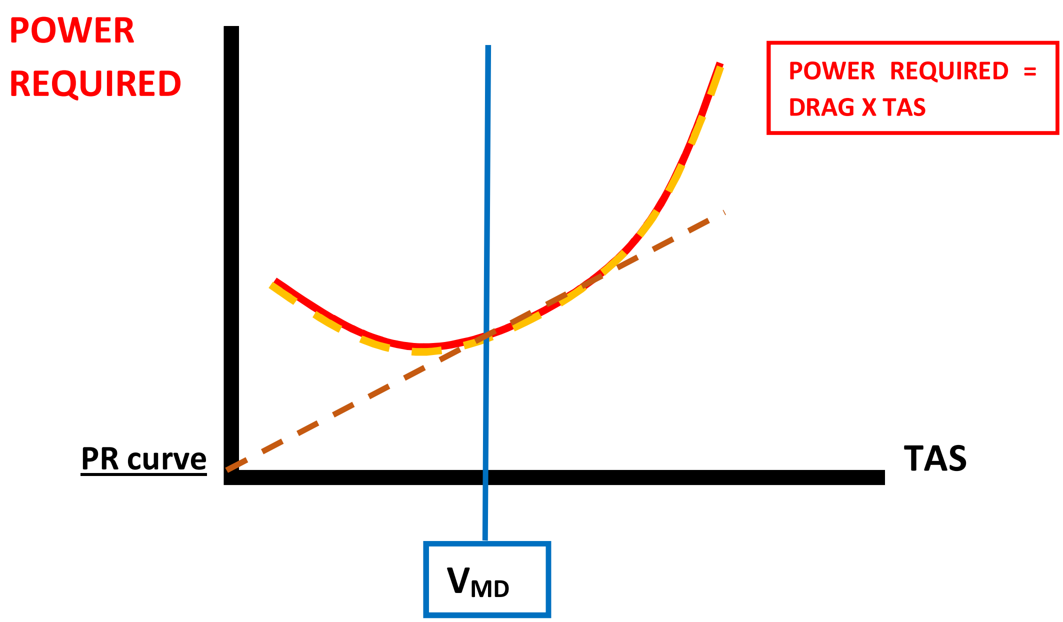


➔ **PROP AEROPLANE**, the **MAXIMUM RANGE** is achieved at $\mathbf{V_{MD}}$

FACTORS AFFECTING

Factors	**Increase best RANGE**	**Decrease best RANGE**
Weight	Light, AFT CG (V_{MD} ↓) (1.32V_{MD} ↓)	Heavy, FWD CG (V_{MD} ↑) (1.32V_{MD} ↑)
Config (flaps)	Flaps retracted, gear up (V_{MD} ↑) (1.32V_{MD} ↑)	Flaps extended, gear down (V_{MD} ↓) (1.32V_{MD} ↓)
Altitude	**BEST ALT** Jet: Tropopause / Prop: 10000 ft / Piston Engine: Sea Level	
Wind	Tailwind ($V_{BEST\ RANGE}$ ↓)	Headwind ($V_{BEST\ RANGE}$ ↑)





SPEEDS SUMMARY

Speed	JET	PROP
Best Endurance	V_{MD}	V_{MP}
Best Range	1.32 V_{MD}	V_{MD}

5) OPTIMUM ALTITUDE

The optimum altitude is the altitude at which the aircraft will have the minimum Fuel Flow and **so achieve the best range**.
For JET aeroplane, the optimum altitude is usually the tropopause since the temperature will be the coldest.

➔ Flying below the optimum altitude will result in reduced range.

However, at high altitudes, the Mach Number will increase and so the aircraft will reach closer to its M_{MO}, resulting to the apparition of a shockwave causing an increase in the total Drag, and so an increase of the Fuel Flow, thus the range will decrease.

➔ Flying above the optimum altitude will result in reduced range.

WEIGHT EFFECT OPTIMUM ALTITUDE

When the weight increases, the best range speed increase ($1.32V_{MD}$), so the Mach Number as well increases, leading to an early apparition of the shockwave causing an increase in the total Drag, and so an increase of the Fuel Flow, thus the range will decrease.

Therefore, the aircraft will have to maintain the best range speed at a lower altitude.

➔ Increasing weight causes a decrease the optimum altitude.

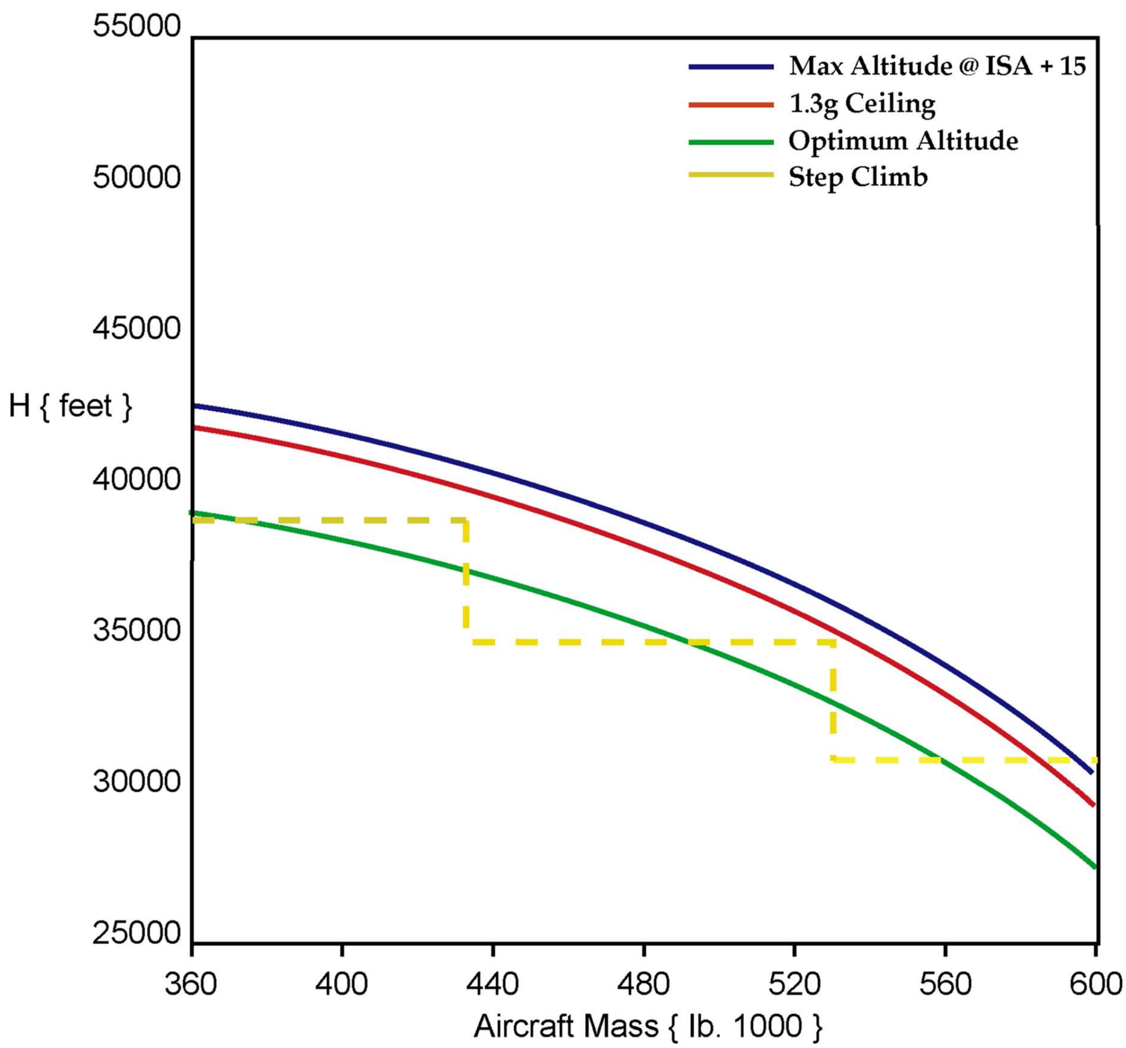
STEP CLIMB or CRUISE CLIMB

As the aircraft consumes fuel in flight, its weight decreases and so the optimum altitude increases during flight. Therefore, to achieve the best range, the aircraft must climb along the flight to maintain the optimum altitude.

Since it’s not obvious to fly at optimum altitude constantly, it is recommended to fly “around”.

The recommended way to fly around is to fly over the optimum altitude by 2000 ft, during the flight the optimum will get closer the aircraft altitude, then it reaches the aircraft altitude, after that it will exceed the aircraft altitude, and meantime the aircraft is flying near its optimum altitude. When the optimum altitude exceeds the aircraft by 2000 ft, then the aircraft must climb 4000 ft to be again 2000 ft above the optimum altitude and to repeat the same procedure.

However, it’s not certified that the aircraft will be able to climb since that depends on ATC as well.



6) LONG RANGE CRUISE (LRC)

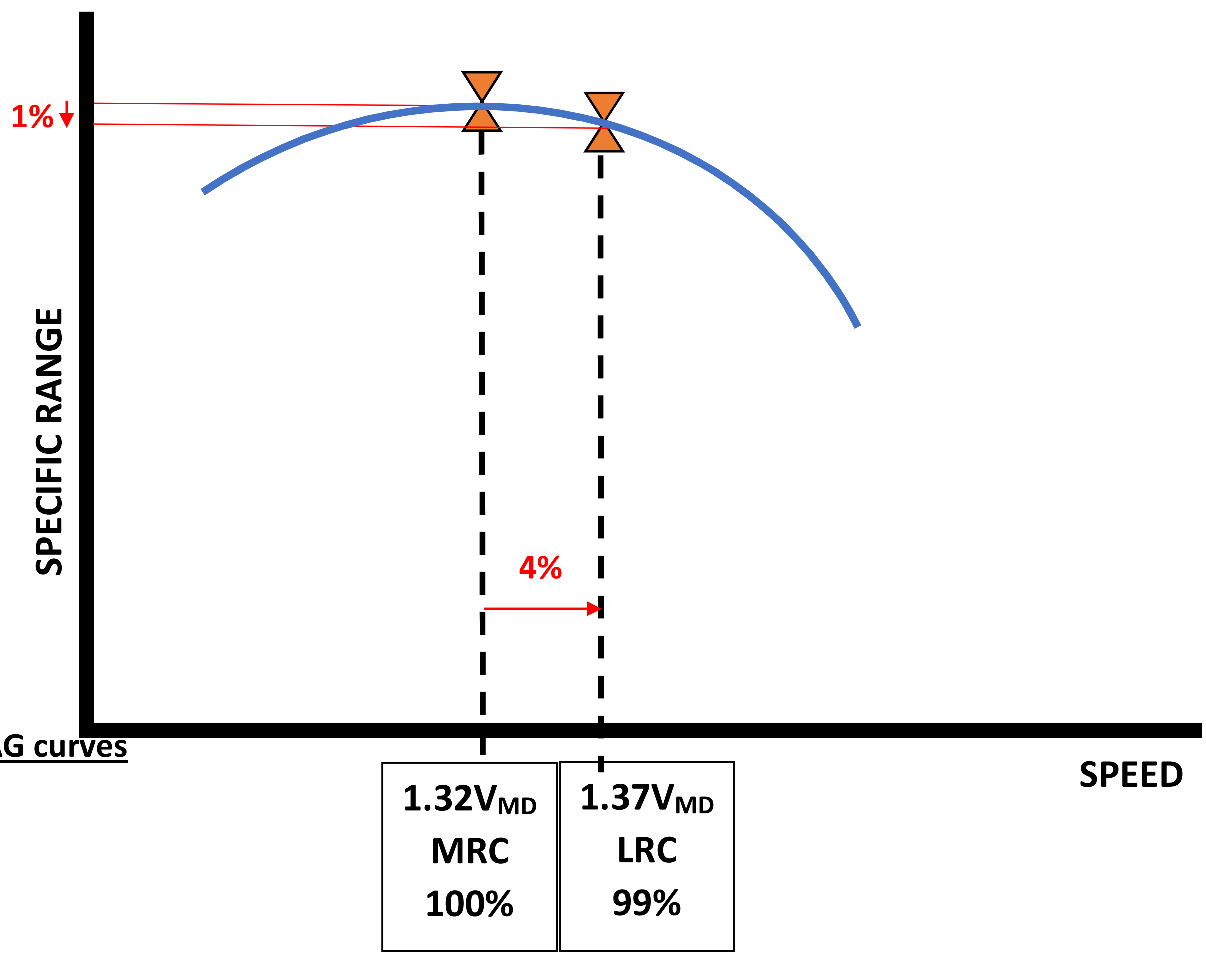
In commercial aviation, the best range speed ($1.32V_{MD}$), is also known as **the Maximum Range Cruise (MRC)**.

Flying at the MRC is to achieve the best range by using the best ratio between TAS/fuel flow. Therefore, it will result in reducing the fuel cost.

However, there are other costs in aviation that the fuel. So, it's sometimes better to increase the speed if that would result in a reasonable increase of the fuel flow.

On the curve below, it can be seen the Specific Range compared to the speed. It is obvious that increasing the speed beyond MRC, will cause a decrease of the specific range. Although, an increase of 4% of the speed, will only lead to a 1% decrease of the Specific Range.

Increasing by 4% the MRC, gives the speed for **LONG RANGE CRUISE (LRC)**



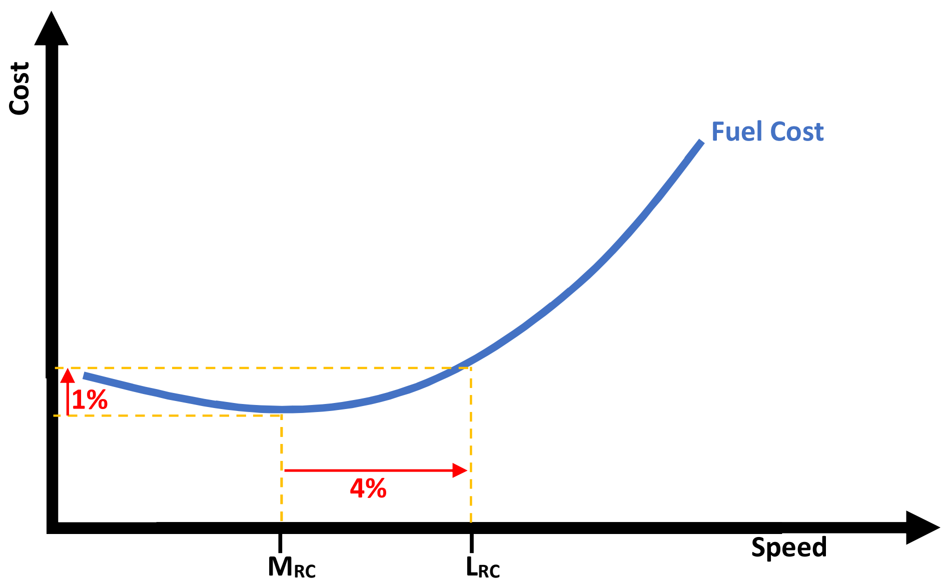
DRAG curves

CRUISE SPEEDS

The first speeds to consider are the maximum operating speeds, either called V_{MO} when using indicated airspeed or M_{MO} when using mach numbers.

For the majority of the 737 family V_{MO} is 340 knots and M_{MO} is 0.82. Flying beyond these speeds in a commercial operational context is not permitted and may cause either structural damage or a high speed stall.

The next speeds to know are used in reference to describe the range of the aeroplane. Those are the Maximum Range Cruise speed, MRC, and Long Range Cruise speed, LRC.
When these speeds are referenced in terms of a Mach number the abbreviation is changed to M_{MR} and M_{LRC} respectively.



The advantage of flying at the maximum range speed is simply that the aeroplane will use the least amount of fuel and therefore have the least fuel cost for a given distance. However, operationally, the faster “long range cruise” is used. The simple reason why this speed is used is because by getting to destination more quickly; more revenue earning flights can be carried out in any given period.
In other words, over a given time, **4% more flights can be carried out with only a fuel consumption increase of 1%**.

The long range cruise speed does suffer from limitations. It doesn’t consider the variable cost of fuel from day to day or month to month and neither does it account for the operational costs. When fuel prices are high, the extra fuel consumption may dramatically increase the overall cost of the flight and a more operationally economical speed may need to be flown.

COST INDEX

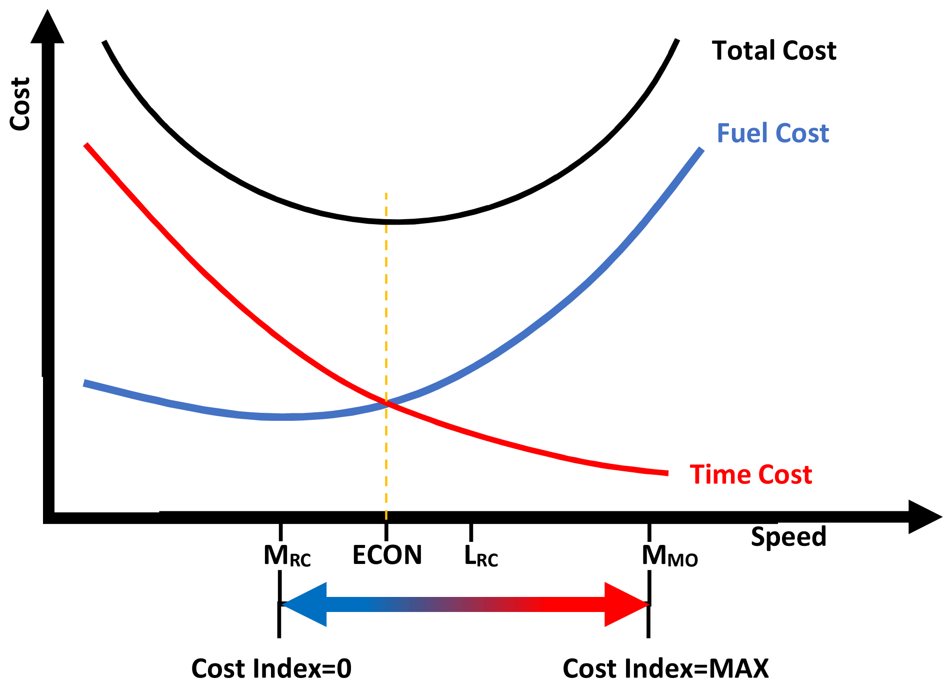
The cost index is used to take into account the relationship between fuel-and time-related costs. With time-related costs, the faster the aircraft is flown, the more money is saved in time costs. This is because the faster the aircraft is flown, the more operations it can cover. It also means that it can operate more between inspections when considering maintenance costs.

These costs are minimum at the maximum operating speed VMO/MMO. However, if the aircraft is flown at such a high speed the fuel burn increases and total fuel cost for the trip increases.

Fuel costs on the other hand will be minimum at the maximum range cruise speed (MRC) and maximum and the maximum operating speed.

Adding the time related costs and fuel related costs together, produces a total operating cost.

The flight management system (FMS) uses the time and fuel related costs to select the best speed to fly.



The total cost curve that the speed which gives the minimum total operating cost is the most economical speed to fly. This speed is called ECON, or the Minimum Cost Speed. The value of the ECON speed is worked out by the FMS based upon the value of the cost index.

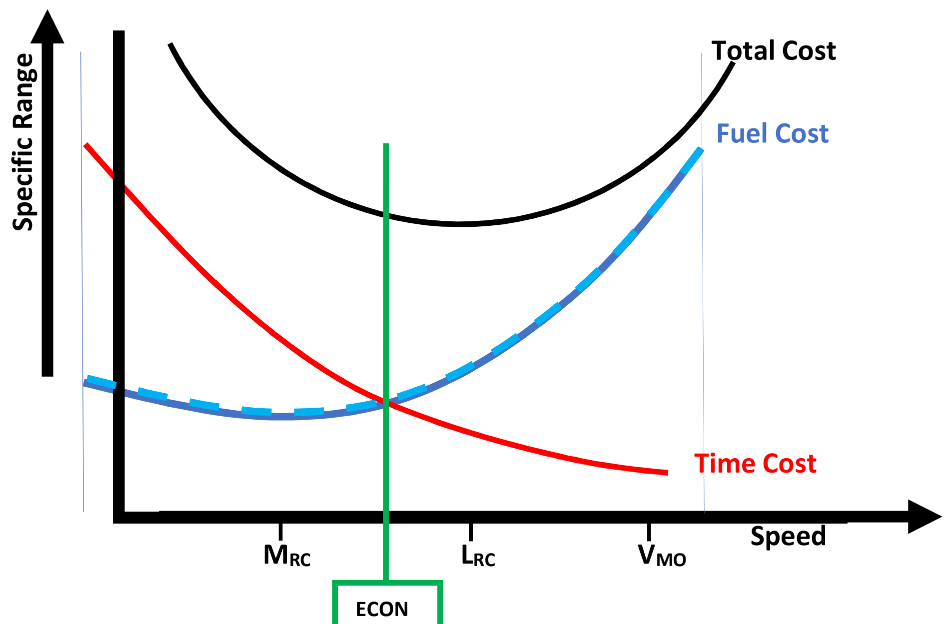
As a formula the cost index is a ratio of cost of time (CT) divided by the cost of fuel (CF).

$$Cost\ Index\ (CI) = \frac{Cost\ of\ Time\ (CT)}{Cost\ of\ Fuel\ (CF)}$$

Fluctuation of the fuel cost

When fuel costs are high and time cost are very low, the cost index would be almost zero and the black total cost line is moved to the left. The intersection point of the other cost lines will lie very close to the maximum range cruise speed and. With a cost index of zero, the ECON speed (found at the bottom of the blue line) would now be at the maximum range speed.

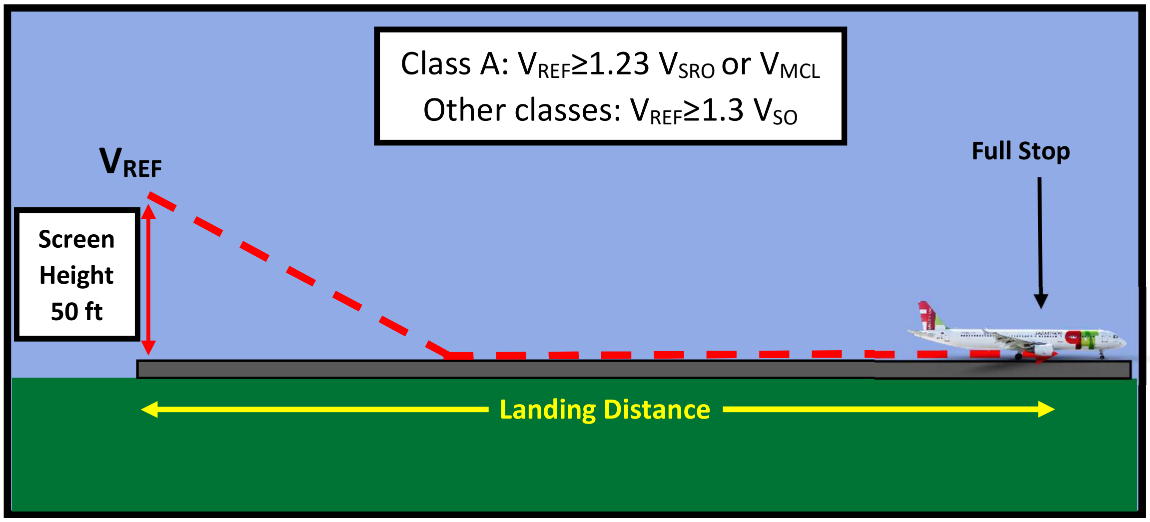
When time costs are high and fuel costs are low, the cost index would be very high, and the black total cost line moves to the far right of the graph. The ECON speed, found at the bottom of the blue curve would now be very close to the maximum operating speed.



To summarise then, increasing the cost index from zero to maximum will increase the ECON speed from the maximum range speed to maximum operating speed. For most aeroplanes the cost index varies from 0 to 99 or from 0 to 999.

D) Landing (LDG)

The landing part of the flight is the distance from 50 ft screen height until the Full Stop.
The screen height is 50 ft for all classes.



From the approach down to the landing screen height the aeroplane must have attained the landing reference speed, known as V_{REF}. V_{REF} for Class A aeroplanes must be no less than the greater of 1.23 times the stall reference speed in the landing configuration (1.23 V_{SRO}) and the velocity of minimum control in the landing configuration (V_{MCL}). V_{REF} for all other classes of aeroplane must be no less than 1.3 times the stall speed (1.3 V_{SO}) in the landing configuration.

Available distances
Landing distance available (LDA): Length of runway from one threshold to another

Affecting factors

Factors	**Increase LDG distance**	**Decrease LDG distance**
Weight	Heavy	Light
Wind	Tailwind (use 150%)	Headwind (use 50%)
Config (flaps)	Flapless	Flaps extended
Density (pressure, temp, humidity)	High pressure alt. High temp, high humid	Low pressure alt. Low temp, low humid
Runway surface	Grass (+15%), contaminated	Paved, dry
Slope	Downslope **Increase 5% LD for each 1% slope**	Upslope
Thrust reverses	Without	With
Spoilers	Without	With

Runway Contamination

Damp Runway: When there is moisture present on the surface which changes its colour, but insufficient moisture to produce a reflective surface.

Wet Runway: When the moisture level makes the runway appear reflective, but there are no areas of standing water more than 3mm deep.

Contaminated Runway: When more than 25% of the runway is covered in a layer of moisture, whose specific gravity is equivalent to a depth of 3mm or more of water

When the runway is contaminated water, snow, slush or ice, this reduce the coefficient of friction and so the braking action.

Braking action	Runway Friction (μ)	ICAO ATC/CREW Report Code
GOOD	0,40 and above	5
MEDIUM GOOD	0,39 – 0,36	4
MEDIUM	0,35 – 0,30	3
MEDIUM POOR	0,29 – 0,26	2
POOR	0,25 and below	1
UNRELIABLE	0	9

Hydroplaning

There are three principal types of aquaplaning or hydroplaning as it is now more commonly known

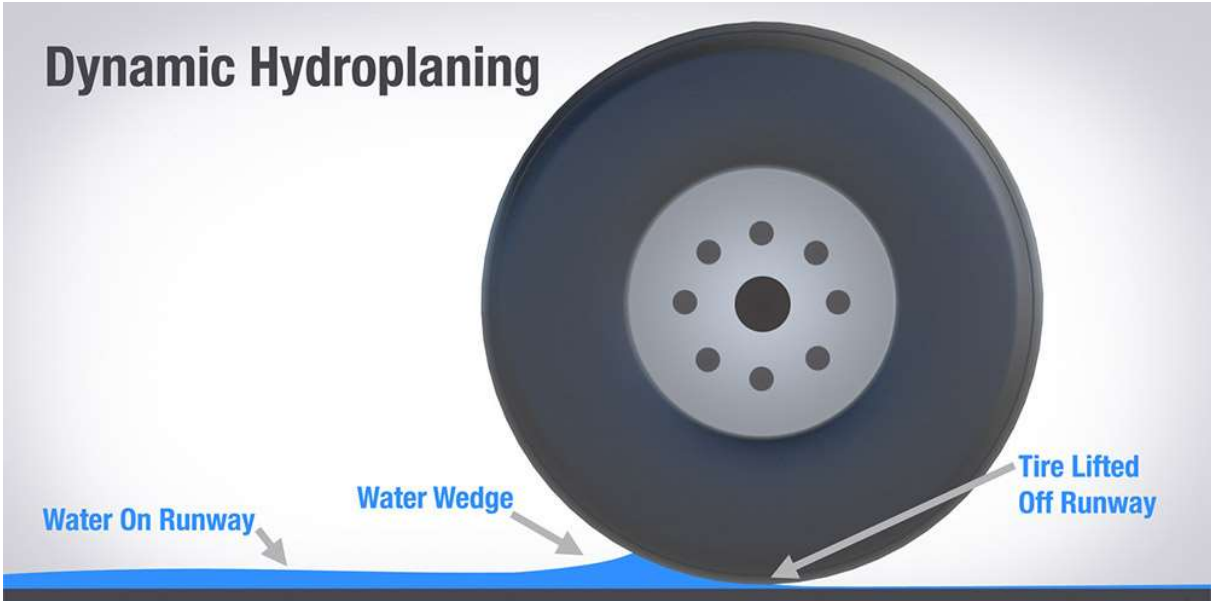
Dynamic Hydroplaning

When an aircraft lands fast enough on a wet runway with at least 1/10 inch of standing water, inertial effects prevent water escaping from the footprint area, and the tyre is buoyed or held off the pavement by hydrodynamic force.
The speed at which dynamic hydroplaning occurs is called VP

For rotating tires: $$VP(kt) = 9\ X\sqrt{Tyre\ Pressure\ (PSI)}$$

For non-rotating tires: $$VP(kt) = 7{,}7\ X\sqrt{Tyre\ Pressure\ (PSI)}$$

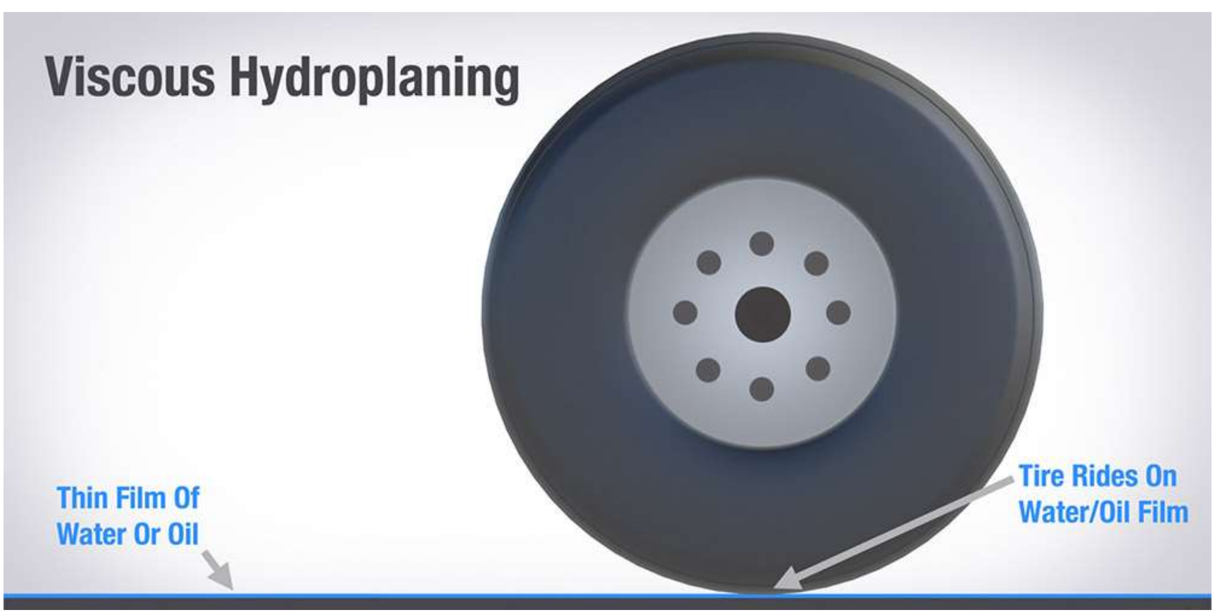
The danger from hydroplaning is the virtually nil braking and steering effect. The most positive methods of preventing this type of hydroplaning is to groove the tires, transversely groove the runway, ensure the runway pavement is convex from the centre line and ensure the runway has a macro-texture.



Viscous Hydroplaning

It occurs because of the viscous properties of water acting like a lubricant. A thin film of fluid not more than 1/1000 of an inch deep cannot be penetrated by the tire in the footprint area and the tire rolls on top of the film. Viscous hydroplaning can occur at a much lower speed than dynamic hydroplaning, but it requires a smooth surface.

The most positive method of preventing this type of hydroplaning is to provide a micro-texture to the pavement surface which breaks up the film of water allowing it to collect into very small pockets. This means that the tyre footprint will sit on the peaks of the textured surface and not the film of water.



Reverted Rubber Hydroplaning

Reverted rubber hydroplaning requires a prolonged, locked wheel skid, reverted rubber, and a wet runway surface. The locked wheels create enough heat to vaporize the underlying water film forming a cushion of steam that lifts the tire off the runway and eliminates tyre to surface contact. The steam heat reverts the rubber to a black gummy deposit on the runway. Once started, reverted rubber skidding will persist down to very low speeds, virtually until the aircraft comes to rest. During the skid there is no steering capability and the braking effect is almost nil.

Reverted rubber hydroplaning is greatly reduced in modern aeroplanes due to the standardization of advanced anti-skid braking systems which prevent wheel lock up.

Landing Technique on Slippery Runway

- **Touchdown within the first 1000 ft on the runway**
- **Apply positive landing**
- **Use Thrust Reverse as soon as possible**
- **Use spoilers**
- **Use AUTO BRAKE accordingly**
- **Apply brakes smoothly and symmetrically**

RUNWAY STRENGTH

The operating mass of the aircraft may be limited by runway strength considerations. The bearing strength of a pavement is expressed by a PCN (Pavement Classification Number) and this is compared to the ACN (Aircraft Classification Number).

Unless prior permission has been obtained from the aerodrome operating authority, the ACN and the tire pressure for the actual weight must not exceed the maximum PCN and the tire pressure published in the AIP.

The PCN code is divided in five sections (e.g. 47 / F / A / W / U):

1- Load Capacity (digit)
2- Rigid (R) e.g. concrete, or Flexible (F) e.g. asphalt pavement
3- Subgrade category strength (A= high, B= medium, C= low, D= ultra-low)
4- Maximum tyre pressure (W= no limit, X= 254 psi, Y= 181 psi, Z= 72 psi)
5- Method (T= Technical evaluation , U= physical testing by usage)

According to ICAO Annex 14 aerodrome, Attachment A

19.1.1 […] occasional minor over loading is acceptable […], the following criteria are suggested:
a) for flexible (F) pavements, occasional movements by aircraft with ACN not exceeding 10% above the reported PCN should not adversely affect the pavement;
b) for rigid (R) or composite pavements, in which a rigid pavement layer provides a primary element of the structure, occasional movements by aircraft with ACN not exceeding 5% above the reported PCN should not adversely affect the pavement;
c) if the pavement structure is unknown , the 5% limitation should apply; and
d) the annual number of overload movements should not exceed approximately 5% of the total annual aircraft movements

Example of question:
Occasional movement of aircraft with an ACN of 50 should not adversely affect the pavement if the reported PCN is at least:

A) 47/F/A/W/U
B) 60/F/A/W/U
C) 60/R/A/W/U
D) 47/R/A/W/U

Solution
For a flexible (F) surface, the ACN can exceed the PCN by 10%:
50/1,1 ≈ 45,45 → the required PCN is 46

For a rigid (R) surface, the ACN can exceed the PCN by 5%:
50/1,05 ≈ 47,62 → the required PCN is 48

Therefore

A) This answer can work because 47 for a flexible (F) pavement isn't exceeded by 110% ACN
B) This answer can work because 60 for a flexible (F) pavement exceed the aircraft ACN
C) This answer can work because 60 for a rigid (R) pavement exceed the aircraft ACN
D) This answer can't work because 45 for a rigid (R) pavement is exceeded by 105% ACN

Since the question is asking for the least, **therefore the correct answer is A**

SUMMARY

FLIGHT PHASE \ FACTORS		Weight		Configuration					Density (press ALT, T°, humidity)		Wind		Runway			
				Flaps			Gears						Surface		Slope	
		Light	Heavy	Up (retract)	Low/Optim	High/Full	Up (retract)	Down (extn)	High	Low	Head	Tail	Dry, paved	Wet, grass	Down	Up
Take-Off	T/O Distance	↓	↑	↑	↓	↑	N/A		↓	↑	↓	↑	↓	↑	↓	↑
	Reject T/O	TO BE DISUCUSSED SINCE THE ACCELERATED STOP DISTANCE WILL DEPEND ON THE SPEED AT WHICH RTO HAS BEEN INITIATED														
Climb	Best Angle	↑	↓	↑	↓	↓↓	↑	↓	↑	↓	↑°FLT PATH	↓°FLT PATH	N/A			
	Max ROC	↑	↓	↑	↓	↓↓	↑	↓	↑	↓	NO EFFECT					
Desent	Min Angle	NO EFFECT		↓	↑	↑↑	↑	↑	N/A in this lesson		↑°FLT PATH	↓°FLT PATH				
Best Glide	Min ROD	↓	↑	↓	↑	↑↑	↓	↑			NO EFFECT					
Cruise	Endurance	↑	↓	↑	↓	↓↓	↑	↓	DEPENDING ON AIRCRAFT TYPE		NO EFFECT					
	Range	↑	↓	↑	↓	↓↓	↑	↓			↓	↑				
Landing	LDG distance	↓	↑	↑↑	↑	↓	N/A		↓	↑	↓	↑	↓	↑	↑	↓
	G/A Perform	↑	↓	↑↑	↑	↓	↑	↓	↑	↓	↑	↓	N/A			

DURING GLIDE	WIND	WEIGHT
ANGLE OF GLIDE FLIGHT PATH	AFFECT	NO EFFECT
RATE OF DESCENT	NO EFFECT	AFFECT

SPEED \ FACTORS	Weight		Configuration		Pressure Altitude	
	Light	Heavy	Clean	LDG config	High	Low
VS	↓	↑	↑	↓	IAS = TAS ↑	IAS = TAS ↓
VMD	↓	↑	↑	↓	IAS = TAS ↑	IAS = TAS ↓
VMP	↓	↑	↑	↓	NO DATA TAS ↑	NO DATA TAS ↓

	VMP	VMD	1,32 VMD	1,37 VMD
JET	Minimum ROD	Best L/D Ratio	Best ROC	Long Range Cruise
		Best angle of climb	Best Range	
		Best angle of glide		
		Best Endurance		
PROP	Minimum ROD	Best L/D Ratio	N/A	N/A
		Best ROC		
		Best Range		
		Best angle of glide		

SPEED V	JET	PROP
Best angle of climb (Vx)	VMD	V < VMD
Best rate of climb (Vy)	1,32 VMD	VMD
Best glide	VMD	
Min Rate of Descent	VMP	
Best Endurance	VMD	VMP
Best Range	1,32 VMD	VMD
Long Range	1,37 VMD	N/A