VIII. FLIGHT MECHANICS

1) Load Factor

When the aircraft is manoeuvred, it will be subject to loads and stress on the airframe.

The normal load is simply the gravity on Earth exerted daily, which is 9,81m/s².

This constant is often rounded up to 10m/s² in the questions.

This normal gravitational constant is written as 1g.

When a body is undergoing a load of 1g, he/she's subject to the normal load, but if he/she's subject to a load more than 1g, so he/she will feel his/her weight/load increased by the same ratio between that load and the 1g load.

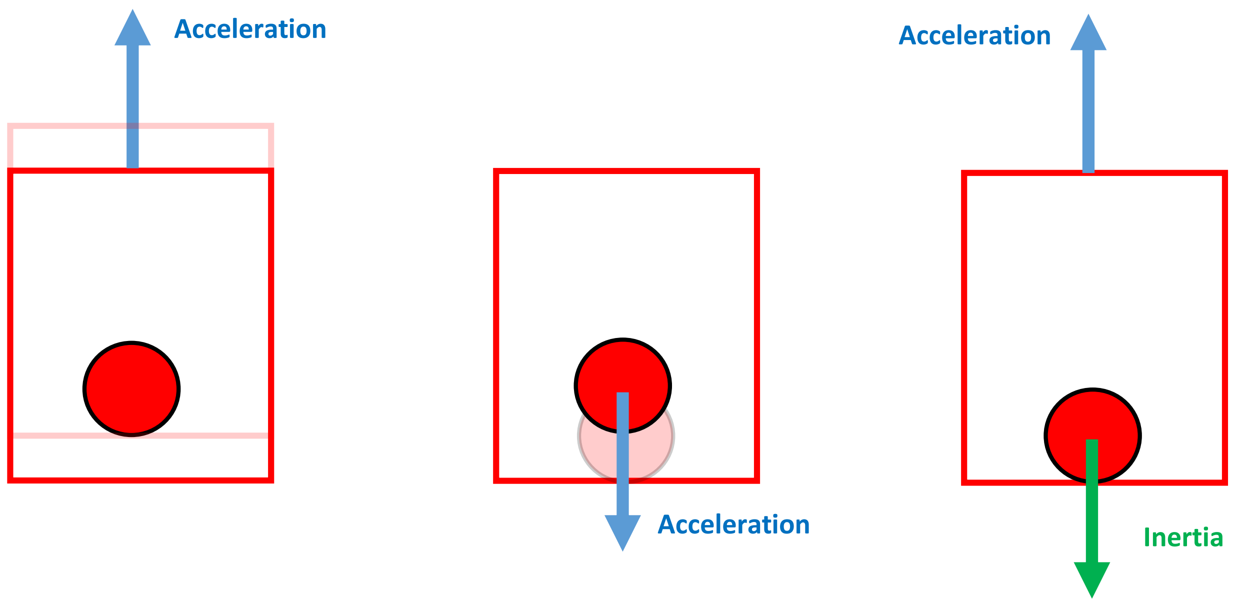
When a body is accelerated in one direction, its inertia will accelerate in the opposite direction.

Inertia is the resistance of any physical object to any change in its position and state of motion. This includes changes to the object's speed, direction, or state of rest.

Inertia is also defined as the tendency of objects to keep moving in a straight line at a constant velocity. The principle of inertia is one of the fundamental principles in classical physics that are still used to describe the motion of objects and how they are affected by the applied forces on them.

When sitting in a car a constant speed, there is no inertia. However when the car accelerates the inertia will make you fill pulled backward until the acceleration is stopped and the speed is kept constant. Also when the car decelerates, the inertia will make you feel pulled forward until the deceleration (negative acceleration) is ceased.

To explain this, let's imagine a ball in a box floating in space. When the bow is pulled (accelerates) upward, the reaction would be the same as if the ball would be pulled (accelerates) downward.



If the inertia is applied downward, in the event of an upward acceleration (example in an elevator), **the body is subject to its weight AND the inertia**, which eventually make "feel heavier". So the body has maximum resistance according to the weight, the inertia may make that limit exceeded which could be dangerous (for a person, the blood is pulled downward, starving the brain from blood and the person faints or a structural failure for the airframe)

In flight, the lift is an upward acceleration (force) "pulling" all object upward. When the lift is equal to the weight. The aircraft (and anything onboard) is subject to its weight only. However if the lift is increased and become higher than the lift, an additional inertia to the weight will be felt and this increase the load felt. That load is called the **LOAD FACTOR**, and it changes by the same factor of the lift change factor, and it is express in **"g"**.

Calculating the load factor is easy, you simply need to find the ratio between the actual LIFT, and the previous LIFT which was equalizing the WEIGHT.

$$Load\ Factor\ (n) = \frac{L}{W}(g)$$

When the lift is equal to the weight, the load factor is 1g, the normal gravity is felt and the aircraft is subject to its normal weight.

When the lift is higher than the weight, the load factor is more than 1g, and the aircraft is subject to more than its "weight"

When the lift is lower than the weight, the load factor is less than 1g.

When the lift is acting downward (negative angle of attack), the load factor is negative (less than 0) and the aircraft feels pulled upward. Note than, to transit from a positive load factor to a negative load factor, it is necessary to transit via 0g. When the load factor is 0, the feeling is like floating in space.

2) Straight & Level Flight

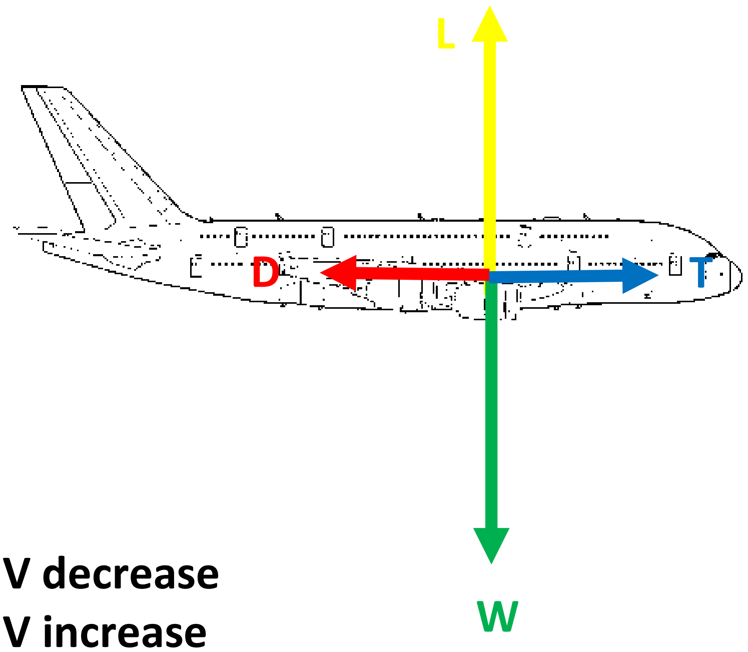
Straight and level flight refers most commonly in when the aircraft is in cruise. However this simply means a flight with a constant altitude and direction.

Straight → same direction

Level → same altitude

Indeed in a straight and level flight at constant, the lift is equal to the weight and the thrust is equal to the drag. Also, the load factor is 1g.

A conventional way to represent this, is to draw those four forces in equilibrium through one point.



$$L = W$$

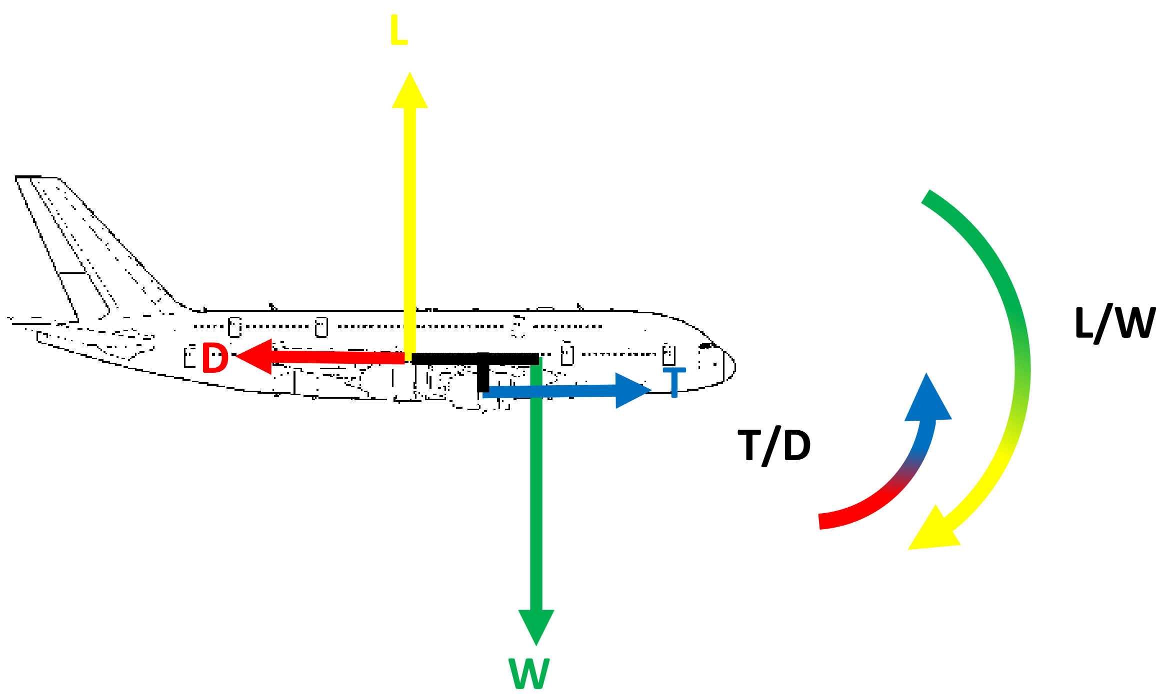
$$T = D$$

$$n = L/W = 1g$$

if T<D, V decrease

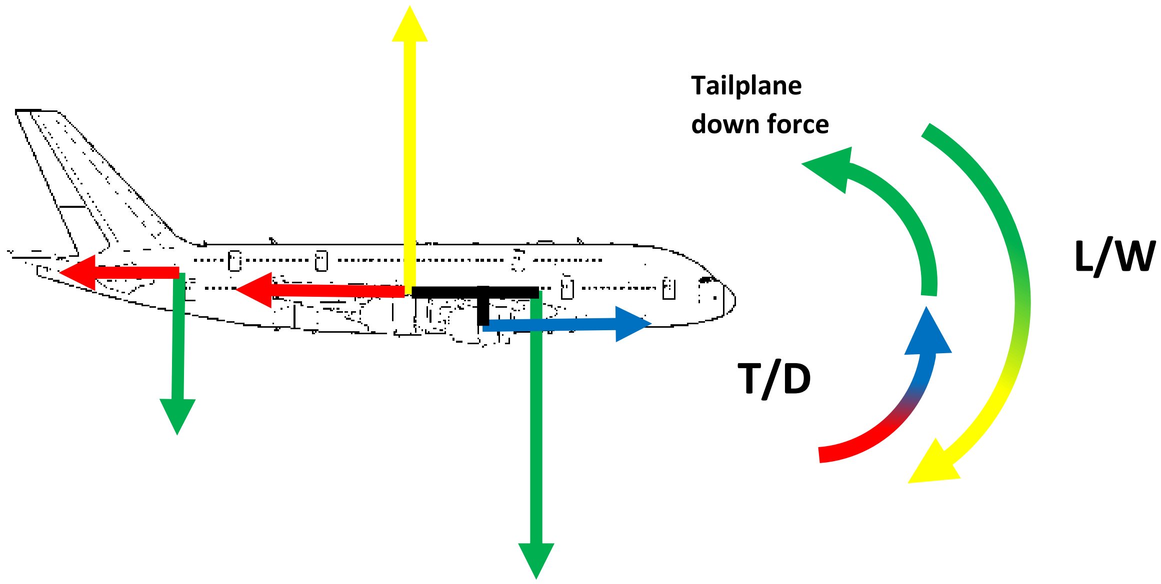
if T>D, V increase

However, if the forces have different sources. The weight is applied through the CG, the lift through the CP, the total drag at the CG, and the thrust from the engines.



After the forces have been drawn from their correct points, it can be seen that different pitching moment exist on the aircraft.

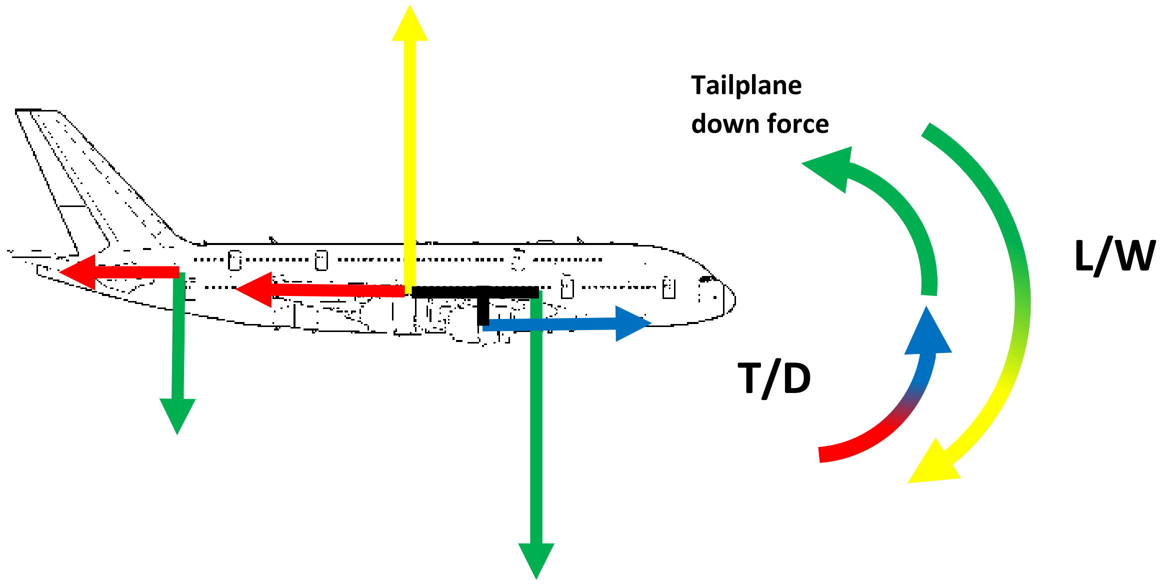
Remember, the aircraft rotates around its CG. The product of the lift and the arm between the CG and the CP will generate a nose down moment. Also, the product between the thrust and the arm between the CG and the engines will generate a nose up moment. Although the nose down moment from the lift is higher than the nose up moment from the thrust. So the aircraft require an additional nose up moment to overcome and to maintain the aircraft stabilised. This nose up will be provided by the tailplane, acting as inverted wing to create a downward aerodynamic force, notice it will also generate drag.

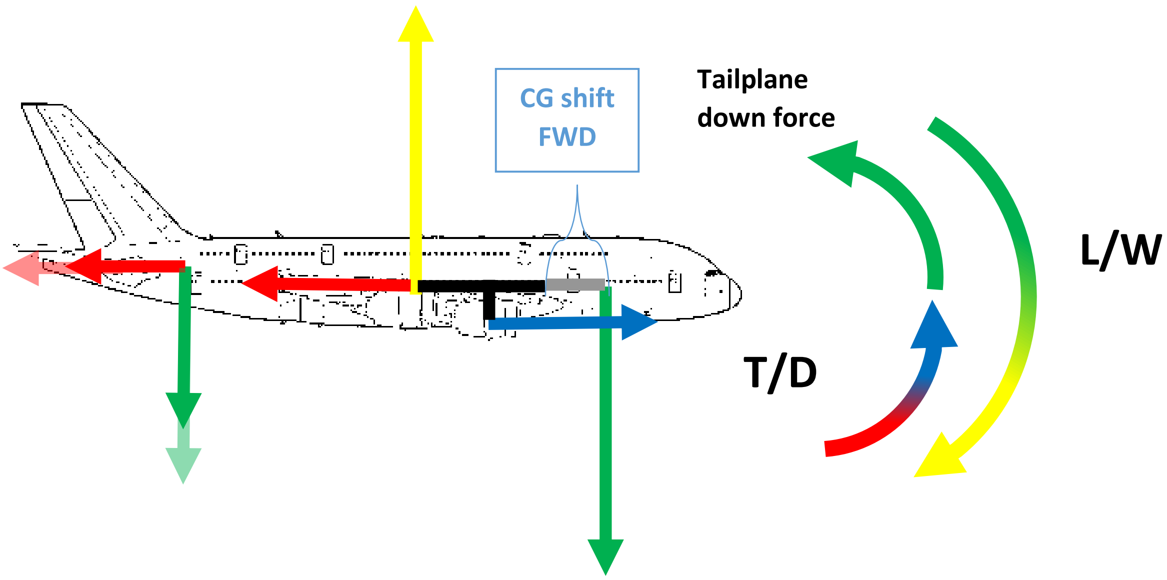


When the CG is forward (FWD), the lift generated from the wings will generate a greater nose down moment to the aircraft. In order to maintain the aircraft stable, the tailplane must deflected up to generate a vertical downward force to keep the nose up. The upward deflection of the tailplane will make it less streamlined into the airflow resulting in an increase of the total drag, that will require more thrust from the engine to be compensated, meaning that the fuel flow (fuel consumption) increases, leading to a decrease of the aircraft maximum endurance and range. Furthermore, the vertical downward force generated by the tailplane will be added to the total weight of the aircraft and make it effectively heavier, thus resulting in an increase of the stall speed and other performances speeds. The total opposite is true when CG is afterward (AFT).

When the CG is forward (FWD), since the aircraft has nose down tendency, this will make it more stable along its longitudinal axis, in the event of a disturbance from an upward gust. Increasing the aircraft longitudinal stability causes a decrease in its longitudinal manoeuvrability. The total opposite is true when the CG is afterward (AFT)

Shifting the CG forward



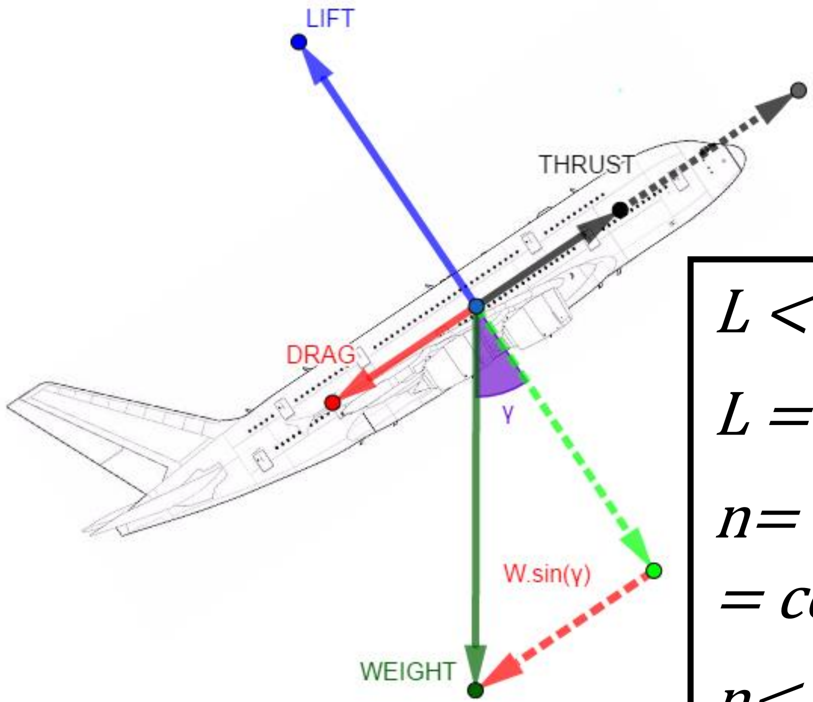


	AFT CG	FWD CG
Effective aircraft weight	↓	↑
Total Drag	↓	↑
V_S	↓	↑
Endurance	↑	↓
Range	↑	↓
Longitudinal static stability	↓	↑
Longitudinal static manoeuvrability	↑	↓

3) Straight Steady Climb

The airplane is in climb when it gains height, its flight path from the ground creates an angle of climb (Ɣ) and this angle will be the angle of tilt of the weigh backward. The weight always acting vertically to centre of Earth, will create two components: one perpendicular to the flight path acting against the lift (W.cos Ɣ) and one backward parallel to the flight path acting as "weight apparent drag" (W.sin Ɣ). Now the initial thrust acting against the drag isn't enough, it must be increased to compensate also for the weight apparent drag in order to maintain the speed (T=D+ W.sin Ɣ). Notice that the lift is less than the weight in climb (L<W), however the airplane is lifted up and climbing, this is thanks to the upward component of the thurst which is significant since the thrust has been increased.

In climb, the load factor "n" is less than 1 since L<W.



$$L < W$$

$$L = W.\cos \gamma$$

$$n = L/W = \cancel{W}.\cos \gamma / \cancel{W}$$
$$= \cos \gamma$$

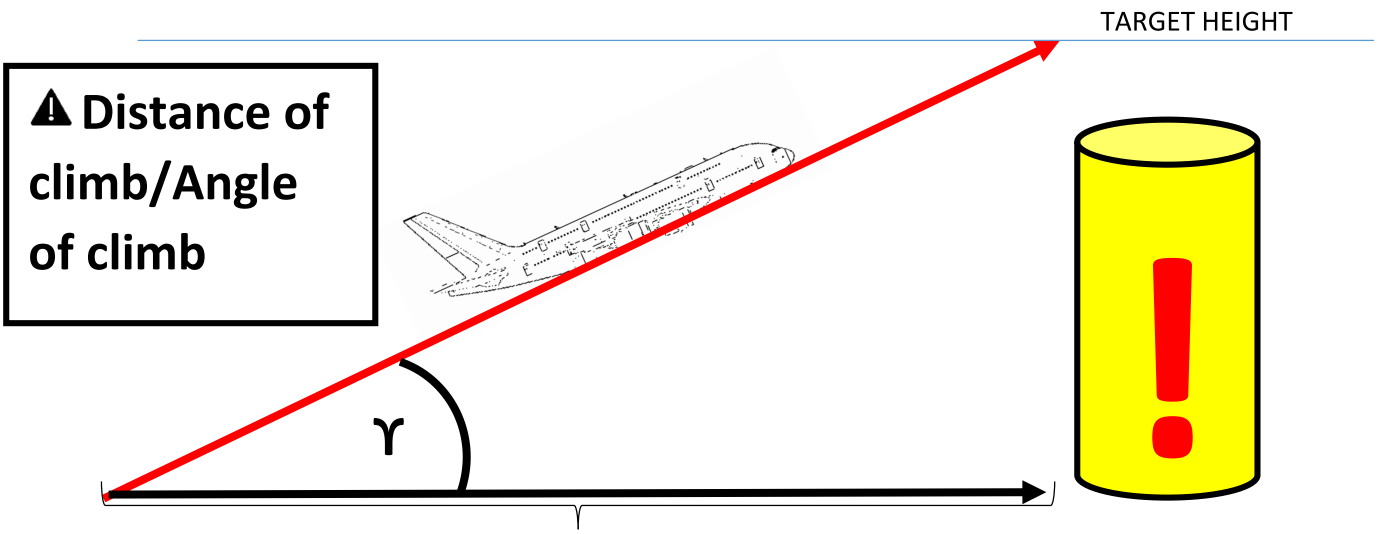
$$n < 1g$$

$$T > D$$

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

There are 2 ways to analyse a climb:
The angle of climb, which is the height gained over the forward air distance
The rate of climb, which is the height gained over a given time.

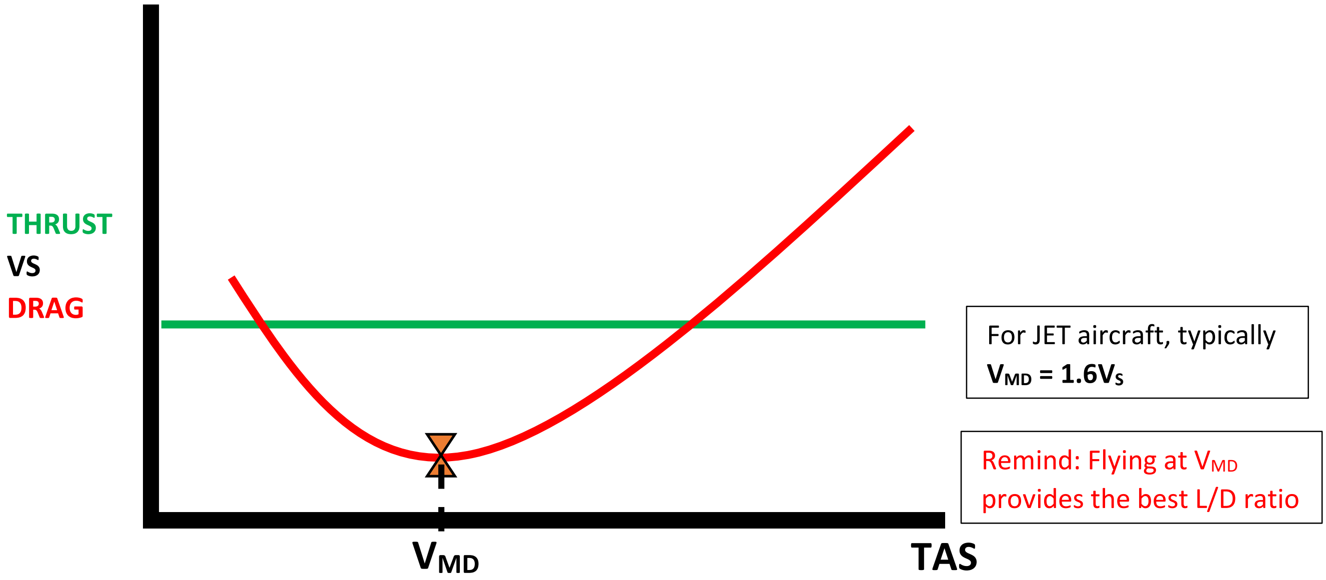
A- Angle of Climb



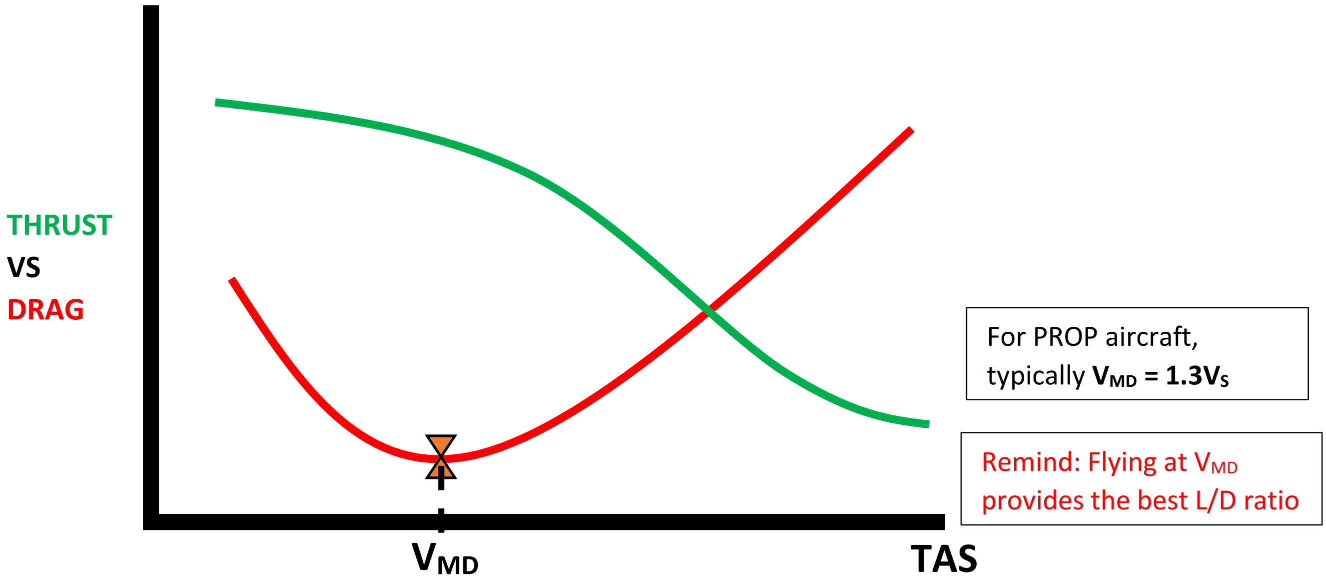
A climb is analysed through the angle of climb when the distance of climb is required to be known, flight planning purpose or clearance a forward obstacle.

Be aware of difference between angle of climb and distance of climb. When the angle of climb is higher, the distance is shorter and when the angle is smaller, the distance is longer.

It has been seen when the aircraft climbs, it must increase its thrust in order to act against the weight apparent thrust. The question is: is that additional thrust available to be provided? For that we need to have a look to the curve of “Thurst available vs the Drag”. We will do that for the jet engine and propeller engine.



JET THRUST vs DRAG curves



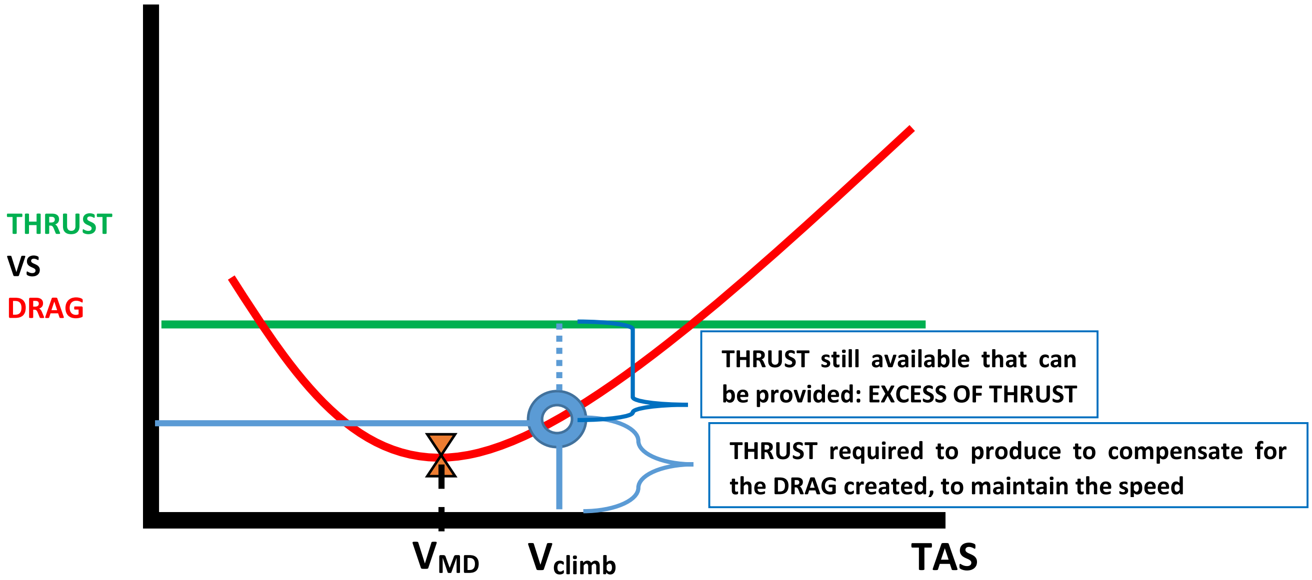
PROPELLER THRUST vs DRAG curves

The thrust curve for the jet engine has been seen previously, regarding the propeller curve we will see how the propeller works and provides thrust at different speed later in the chapter “Propeller”.

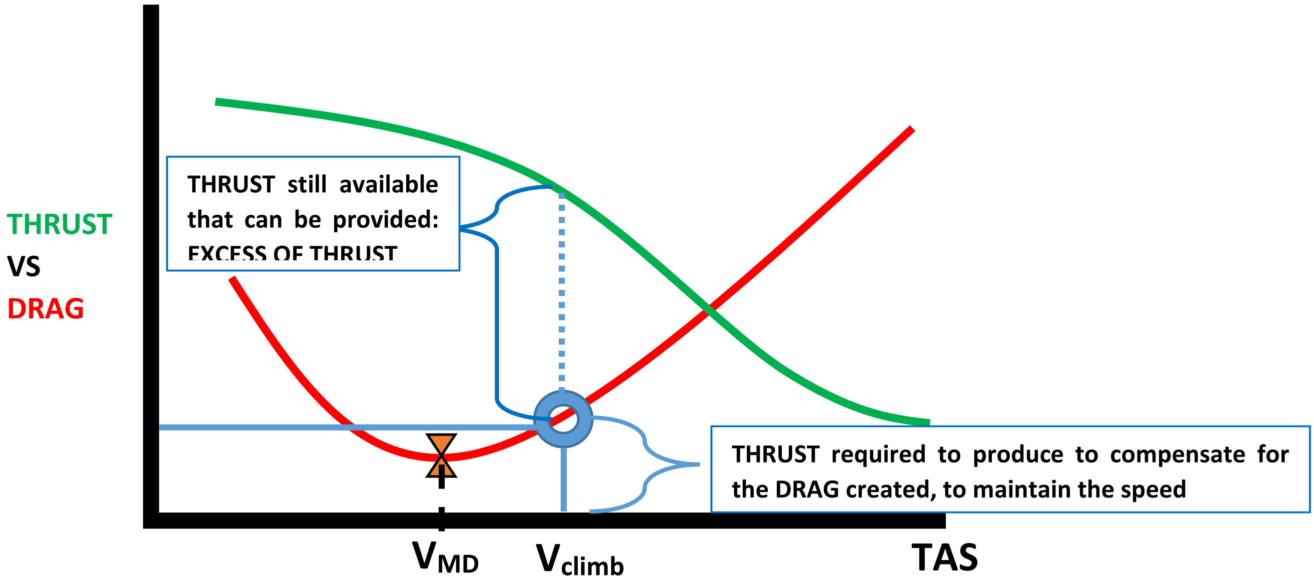
Now that the curves have been introduced, let’s understand how high could be the angle of climb.

When the angle of climb is increased, the distance is reduced and the height gained increases, however the weight apparent climb also increases, which required the thrust to increase further

Let's pick up a speed at which the climb is made, we'll call this speed $\mathbf{V_{climb}}$



JET THRUST vs DRAG curves



PROPELLER THRUST vs DRAG curves

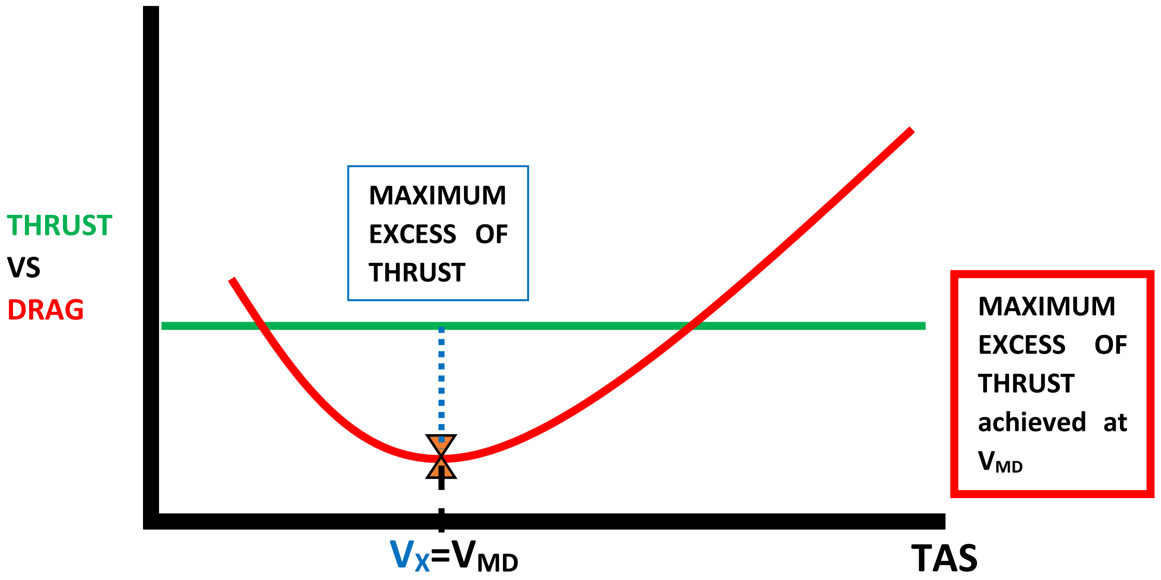
When climbing at V_{climb}, the excess of thrust in pointed blue line can be provided to compensate for the weight apparent drag, however the weight apparent drag should not exceed the excess of thrust at that speed because the pilot wouldn't be able to compensate for it and the speed will start to decrease.

Let's imagine the pilot is climbing at V_{climb} at an angle of climb at which the weight apparent drag is equal to the excess of thrust, so the engine are providing the maximum thrust, however if the pilot increases the angle in order to clear an obstacle, the weight apparent drag will increase and he/she won't be able to increase more the thrust to compensate for it, so the speed will start to decrease. So he/she will have to reduce the angle to maintain the speed.

Therefore if the pilot wishes to climb at a higher angle, he/she will have to climb at speed where the excess of thrust is high in order to compensate for more weight apparent drag. The highest angle of climb that can be maintained is the one where the aircraft has the maximum excess of thrust since it’s the maximum weight apparent drag that can be compensated.

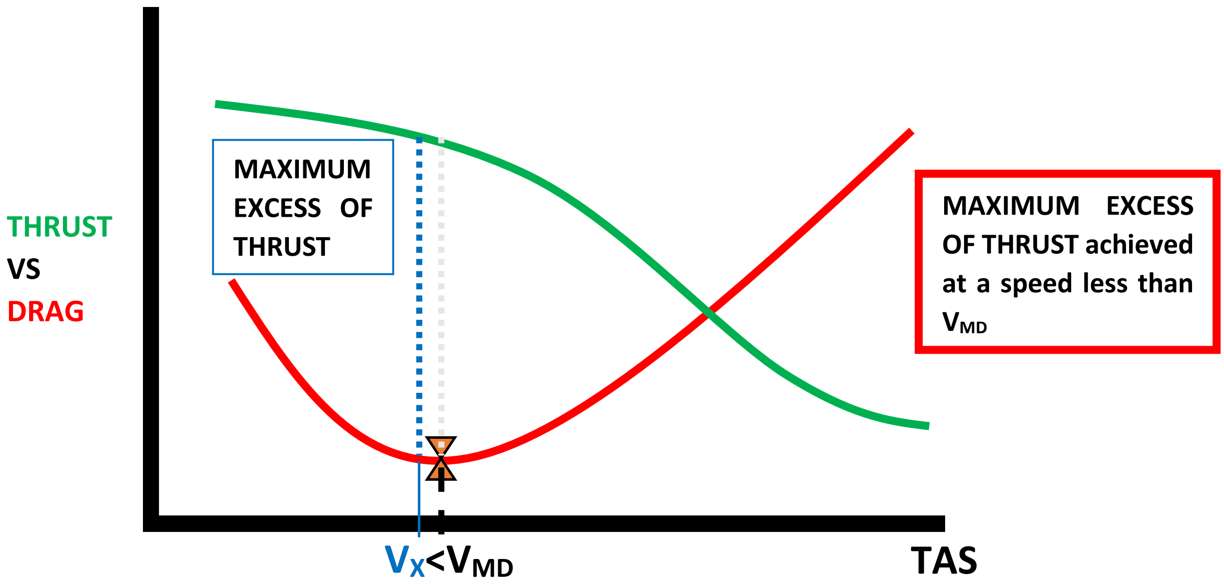
The speed which provides the maximum excess of thrust can be found on the curves by looking at the highest margin between the drag and the thrust available.

At this speed, the highest or best angle of climb can be flown, this speed is called **V_X, the best angle of climb speed.**



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

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



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

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

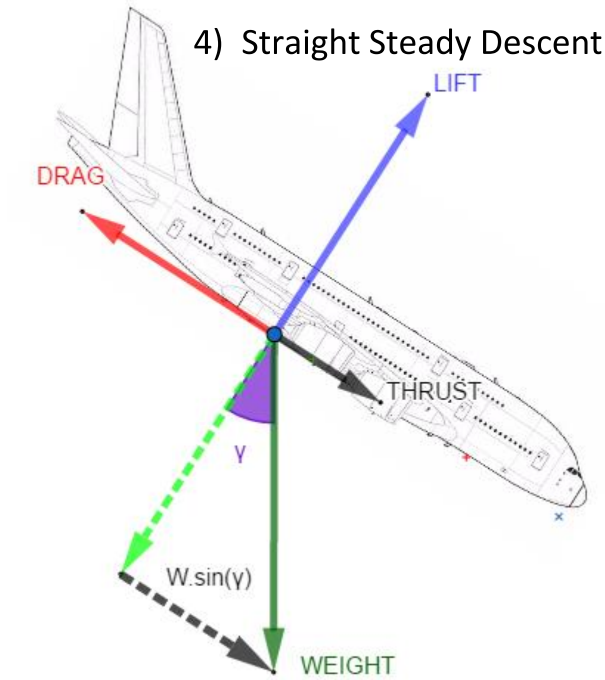
To calculate the Gradient of climb:

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

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

$$Gradient\ (\%) = (\frac{Thrust}{Weight} - \frac{1}{\frac{L}{D} ratio})\ X\ 100$$

4) Straight Steady Descent



$$L < W$$

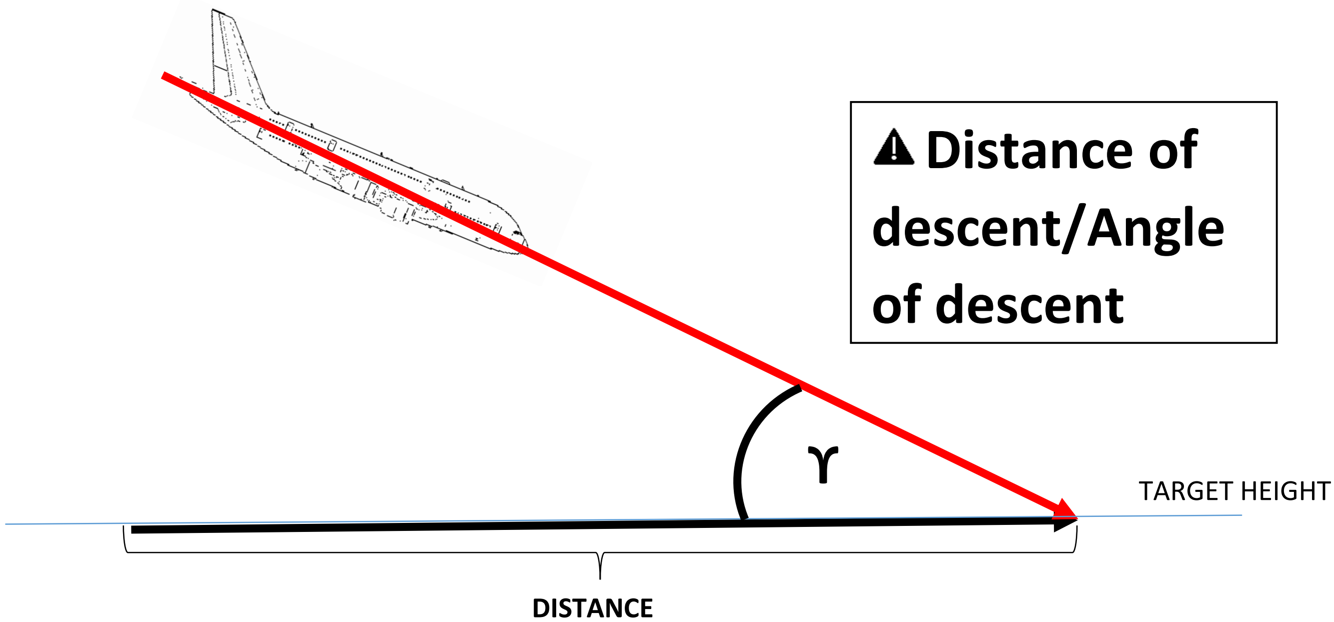
$$L = W.\cos \gamma$$

$$n = W.\cos \gamma / W = \cos \gamma$$

$$n < 1g$$

$$D > T$$

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



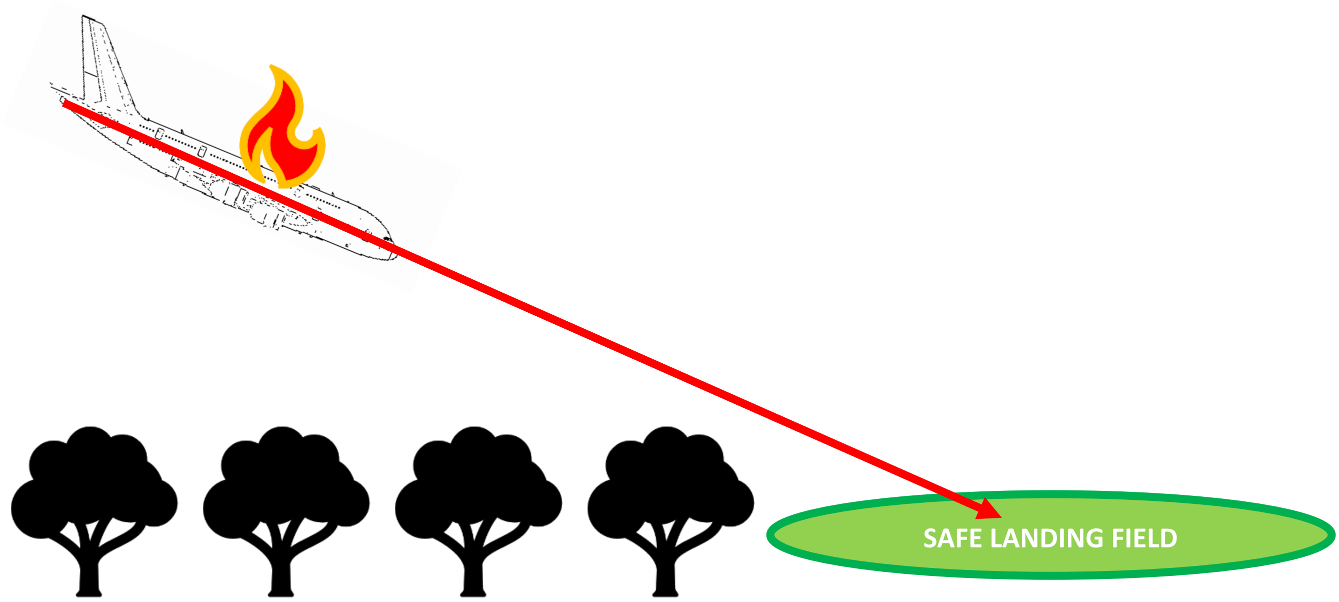
⚠ Distance of descent/Angle of descent

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

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

$$Gradient\ (\%) = \left(\frac{1}{\frac{L}{D} ratio} - \frac{Thrust}{Weight}\right) X\ 100$$

Glide



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

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

GLIDE

1) ANGLE OF GLIDE – DISTANCE OF GLIDE

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) RATE OF DESCENT

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

FACTORS AFFECTING

Factors	**Decrease minimum ROD**	**Increase minimum ROD**
Weight	Light (V_{MP} 🡇)	Heavy (V_{MP} 🡅)
Config (flaps)	Flaps retracted, gear up (V_{MP} 🡅)	Flaps extended, gear down (V_{MP} 🡇)
Wind	No effect	

NOTE: V_{MP} is lower than V_{MD}

DURING GLIDE	WIND	WEIGHT		
ANGLE OF GLIDE FLIGHT PATH	**AFFECT**	**NO EFFECT**	**Best glide**	VMD
RATE OF DESCENT	**NO EFFECT**	**AFFECT**	**Min Sink Rate**	VMP

Load Factor change with pitch:

When pulling suddenly from a dive, the rapid change of the AoA can cause the LIFT to be 4 times more and increase the LOAD FACTOR up to +4g.

When the nose is pushed suddenly following a climb, the AoA will be negative and create a negative LIFT, leading to a significant negative g (-4g). During the transition to the negative g, the aircraft will pass through 0g where no gravity is felt.

5) Turning

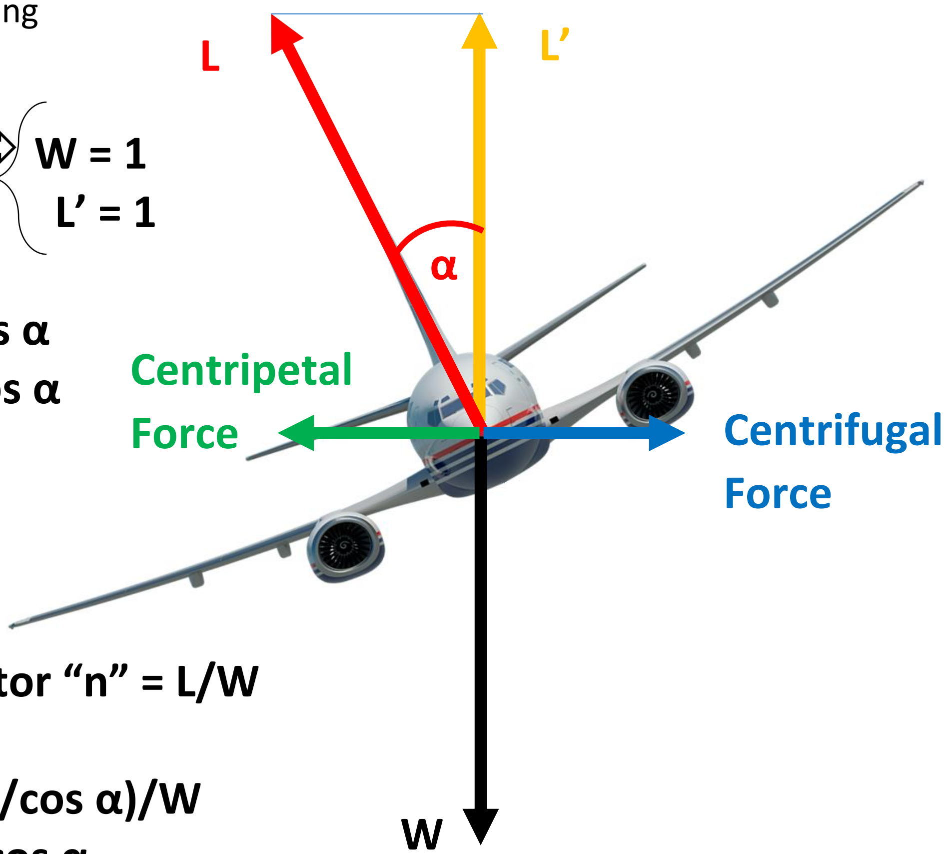
In turn

W = L' ⇔ W = 1
L' = 1

L = L'/cos α
L = W/cos α

T=D

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



$$\boldsymbol{Radius\ of\ Turn\ (r) = \frac{V^2}{g.\tan\alpha}}$$

$$\boldsymbol{Rate\ of\ Turn\ = \frac{360\ x\ TAS}{2\pi r}}$$

$$\boldsymbol{Rate\ of\ Turn\ = \frac{360\ x\ g.\tan\alpha}{2\pi V}}$$

BANK ANGLE to calculate quickly in flight= TAS/10 + 7

If the speed is doubled,

$$Radius\ of\ Turn = \frac{(2V)^2}{g.\tan\alpha} = 4\frac{V^2}{g.\tan\alpha}$$

So Rate of Turn,

$$Rate\ of\ Turn\ = \frac{360\ x\ 2TAS}{2\pi 4r}$$

$$Rate\ of\ Turn\ = \frac{2}{4}\ x\ \frac{360\ x\ TAS}{2\pi r} = \frac{1}{2}\ x\ \frac{360\ x\ TAS}{2\pi r}$$

So the Rate of Turn will be halved if the speed is doubled