DOCUMENT

GSM-G-CPL.002

DOCUMENT TITLE

AERODYNAMICS 1

CHAPTER 10 – AIRCRAFT IN FLIGHT (MANOEUVRE ENVELOPE)

Version 1.0

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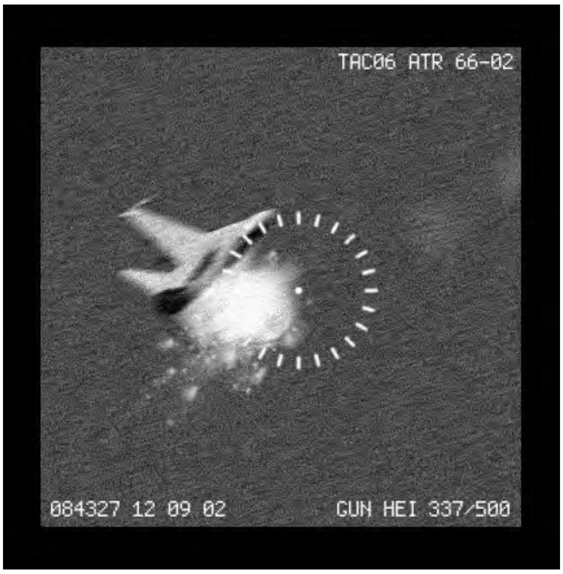
MANOEUVRE ENVELOPE

INTRODUCTION

In modern air-to-air combat it is said that if there is not a clear winner within 45 seconds of the engagement starting, then there will be no winner. Considering that modern combat aircraft can operate at supersonic speeds and close to their limitations, it is of utmost importance that the pilot must know when he is approaching a dangerous situation that may result in structural damage or even total destruction of the aircraft.



These boundaries within which the aircraft must be operated, are graphically depicted by means of a manoeuvre envelope.

DESCRIPTION AND PURPOSE

The manoeuvre envelope is a graphic representation of the operating limits of an aircraft.

It is used for the following:

- To lay down design requirements for a new aircraft.
- By manufacturers to illustrate the performance of their products.
- As a means of comparing capabilities of different types of aircraft.

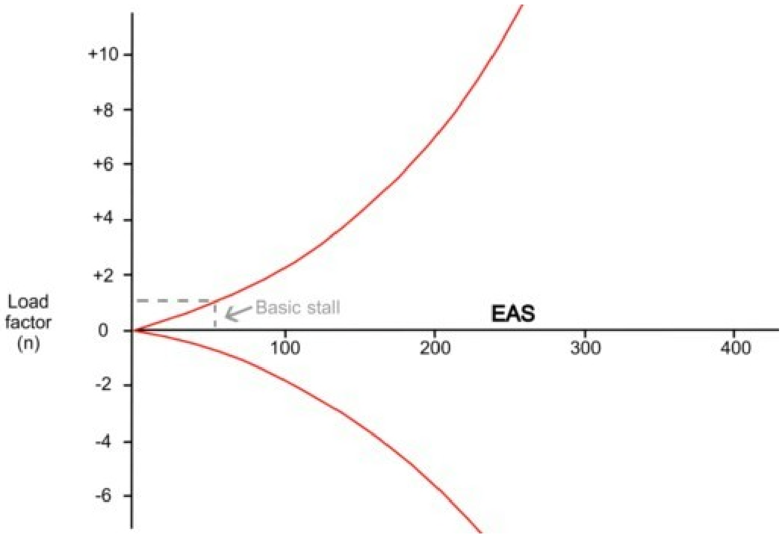
CONSTRUCTION

MANOEUVRE STALL SPEED

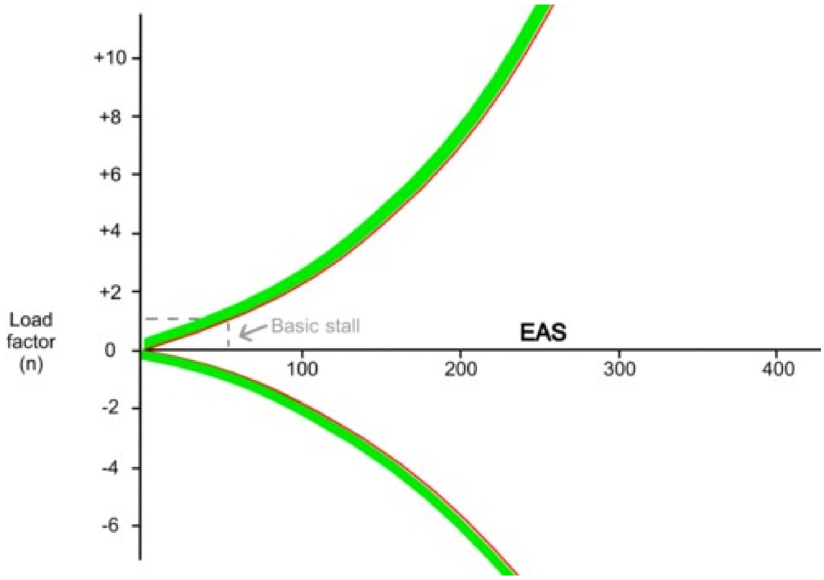
The formula for manoeuvre stall speed is:

$$V_M = V_B \sqrt{n}$$

The **manoeuvre stall speeds** can be plotted graphically with EAS on the x-axis and load factor on the y-axis.



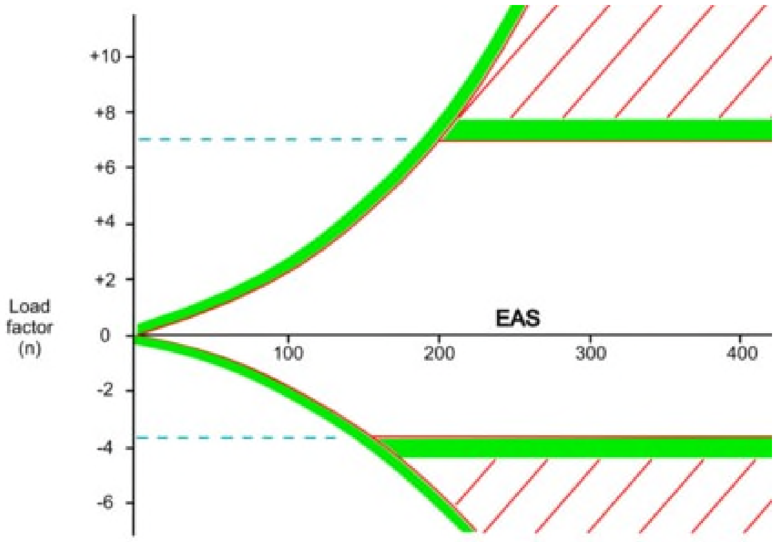
Note that the graph starts at a load factor of 0. When the **basic stalling speed** ***(measured at 1 g)*** is plotted, it is apparent that flight **below** the basic stalling speed is perfectly feasible at load factors below one.

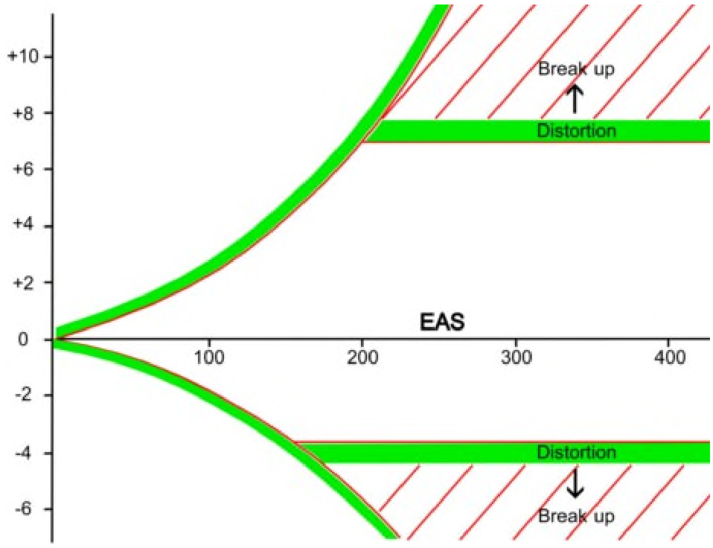


In the **areas** to the left of the manoeuvre stall speed lines the aircraft will be stalled.

"G" LIMITATIONS

All aircraft are designed to certain strength requirements. A typical training aircraft will have **limitations of +7g and -3g**.

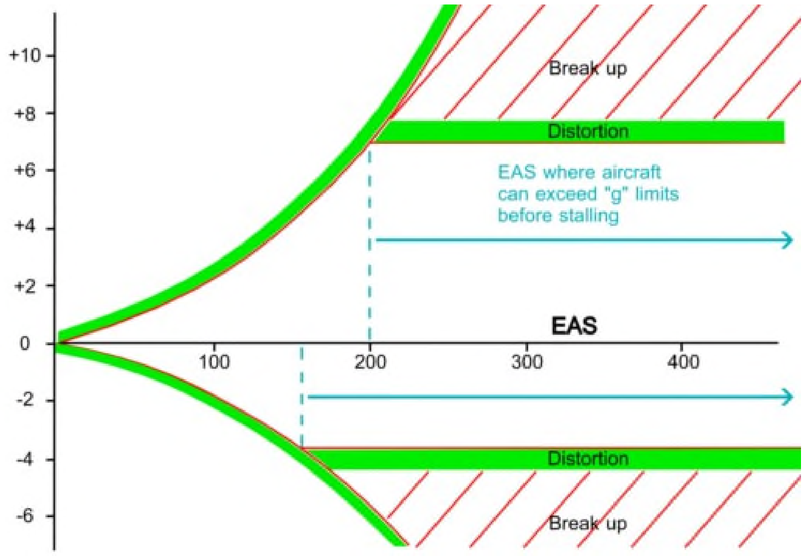




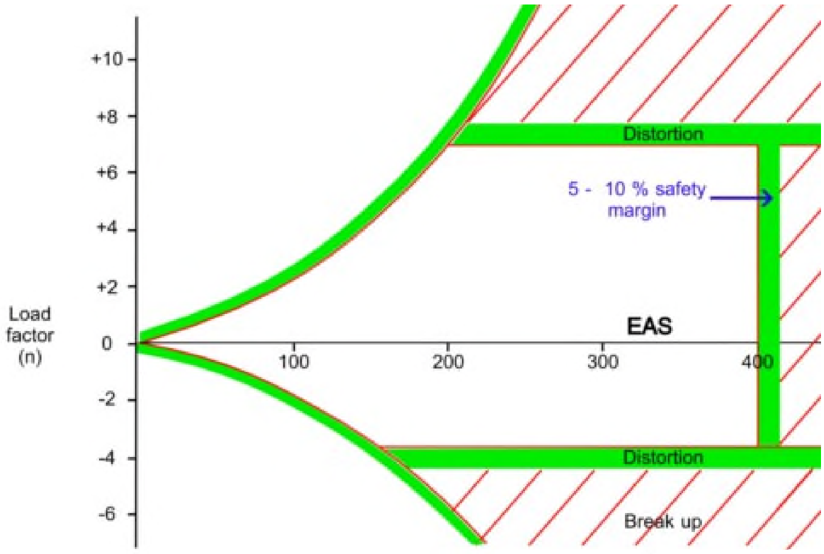
The "g" limitations specified for an aircraft usually have a **50% safety margin** above which permanent deformation and failure may occur.

The "g" limitations are specified for a specific weight. Should the weight of an aircraft increase, then the limiting "g" must be reduced to provide the same safety margins.

From airspeeds above where the **manoeuvre stall and the "g" limitation lines intersect**, the aircraft can exceed the "g" limitations before stalling. Below this point the aircraft will stall before reaching the "g" limitation.

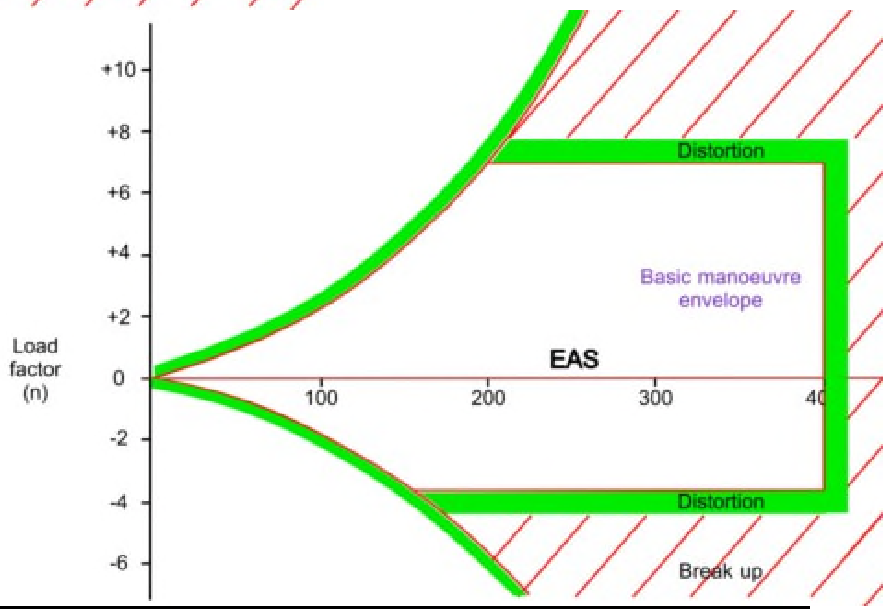


EAS LIMITATION



Every aircraft has a maximum speed limit. Beyond this limit the aircraft may be damaged, ranging from losing panels to total structural failure. Again there is a **safety factor (5 - 10%)** built in.

This completes the basic manoeuvre envelope. Operations outside the basic manoeuvre envelope are either impossible or unsafe.

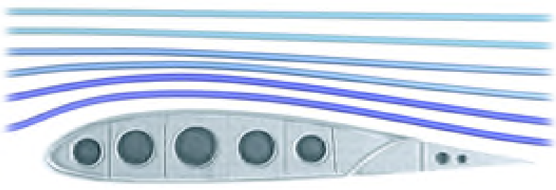


FACTORS AFFECTING $C_{L\,MAX}$

The basic manoeuvre envelope has been constructed on the assumption that the maximum value of C_L is always the same. But there are several factors that can affect the value of $C_{L\,max}$.

COMPRESSIBILITY

Consider an aerofoil moving through the air. The velocity of the airflow is the greatest in the flow close to the aerofoil.



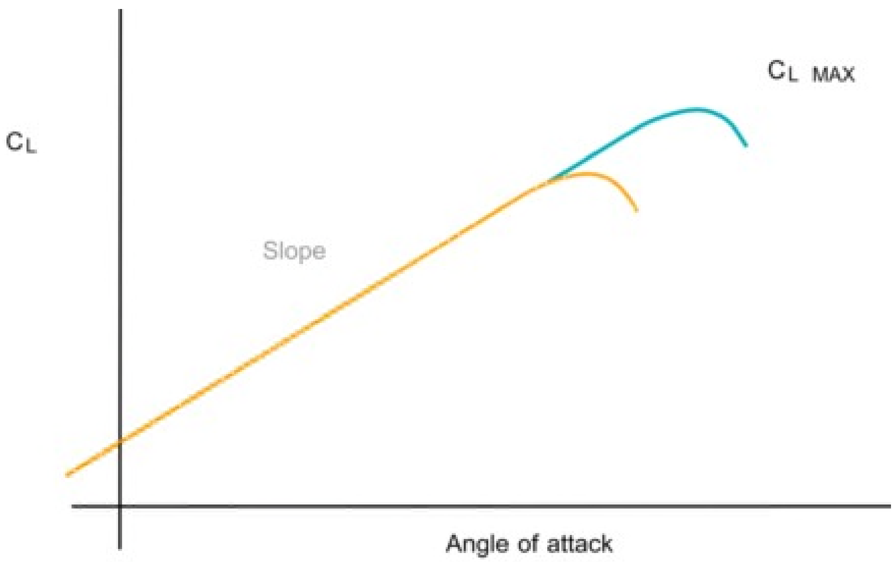
If the free stream flow is close to the speed of sound, the airflow close to the wing may be supersonic due to compressibility and the associated shock wave/s. This will reduce the value of $C_{L\,max}$. ***(This will be discussed in detail in the lesson on Supersonic Aerodynamics)***

The reduction in $C_{L\,max}$ due to compressibility increases as the angle of attack increases. This is because the acceleration of the airflow over the wing is the highest at large angles of attack.

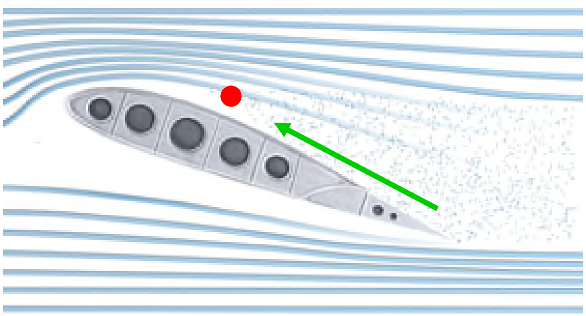
REYNOLDS NUMBER

A change in Reynolds number only has a small effect on the slope of the C_L curve, but because it affects separation at high angles of attack, it will affect the value of $C_{L\,max}$.

If the Reynolds number should increase, it will also **increase** the value of $C_{L\,max}$.



BOUNDARY LAYER



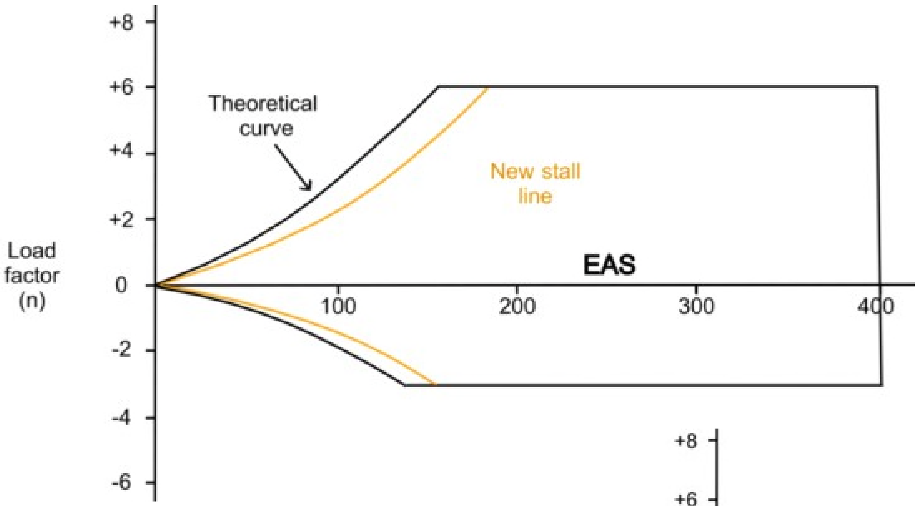
At high angles of attack the **separation point** moves **forward**. This has the effect to thicken the boundary layer.

The thickened boundary layer has the effect of:

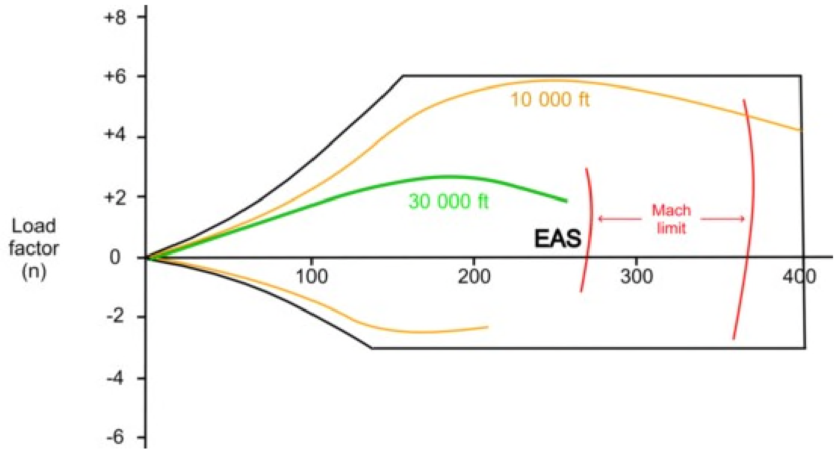
- Decreasing the effectiveness of the tailplane and elevator.
- The fluctuating wake behind the wing makes it impossible to hold accurate angles of attack near the stall. Thus a lower angle has to be chosen.
- Swept wing aircraft may experience pitch-up due to wingtip stalling or an increase in downwash over the tailplane. Again this limits the useable angles of attack near the stall.

The actual effect on $C_{L\ max}$ depends on each wing, but in general it means that the theoretical $C_{L\ max}$ cannot be used. The manoeuvre envelope must thus be modified to take this into account.

MODIFIED MANOEUVRE ENVELOPE



Because $C_{L\ max}$ is reduced, **new stall lines** ***(with positive and negative load factors)*** must be drawn in. These lines will be applicable to sea level.



Since the value of $C_{L\ max}$ reduces with altitude, new curves must be drawn for higher altitudes, for example **10 000** feet and **30 000** feet.

As the stall lines change with altitude, so they will also change with different aircraft weights. Note that the stall lines are also called the **lift boundary** lines.

As an aircraft has an upper limit in its speed range (EAS), so it will also have an upper limit pertaining to **Mach number**.

Shock waves

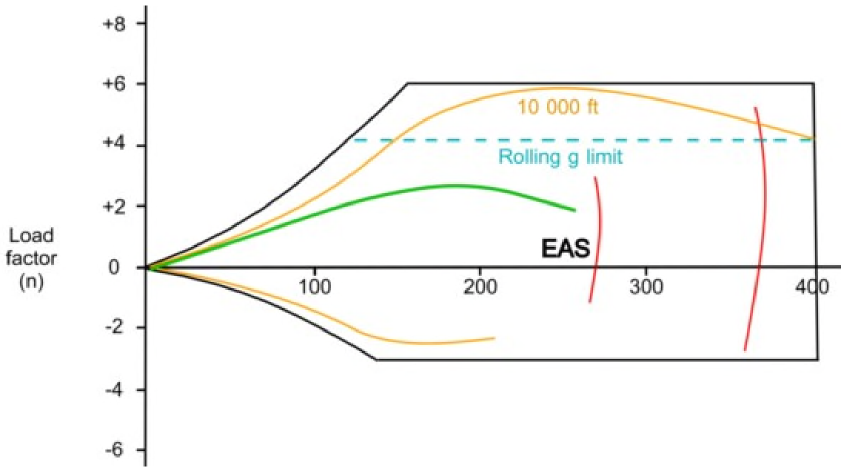
Shock waves are formed when the airflow at any point on the aircraft, but usually on the wings, reaches the speed of sound. The air is then "bunched" together as a wave. Inside this wave, there are drastic changes in pressure and the speed of the airflow.

This limitation is due to compressibility and the formation of shock waves.

Again the **mach limit lines** must be drawn for each altitude because the EAS/Mach number relationship changes with altitude.

Note that the mach limit lines are curved. This is for the same reason as how compressibility affected $C_{L\ max}$, ie. at high angles of attack there is the greatest acceleration of the airflow over the wing. This means that at high angles of attack ***(high load factor)*** the mach limit will be reached at a lower EAS.

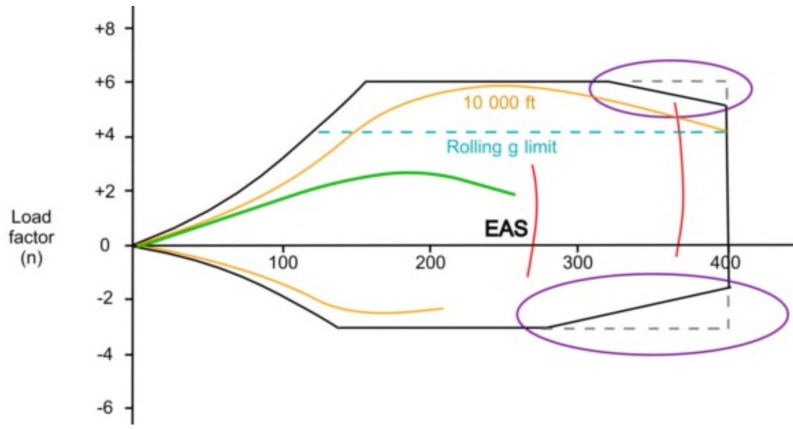
Refer to the definition of Asymmetric loading, which was discussed in the lesson on Turning. The rolling g limit stipulated for an aircraft will be less than the basic load factor limit.

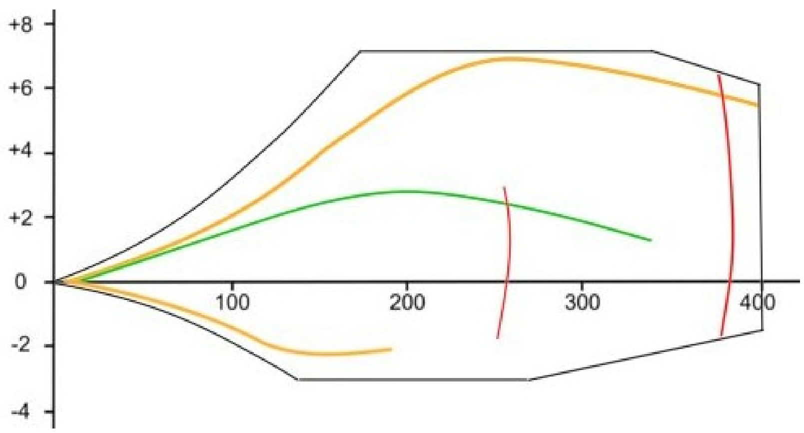


The **rolling "g" limit** provides a safety margin against structural failure because the wing structure must provide strength to withstand the twisting forces caused by the roll control deflection besides providing strength to withstand the normal "g".

If high air loads ***(airspeed)*** are combined with high loadings, the weakest part of the structure is more likely to fail. In the case of the tailplane this will be further aggravated if it is **buffeted** by the turbulent wake of the wings.

This buffeting requires the maximum load factors to be reduced at high EAS. To facilitate this, **buffet corners** are incorporated into the manoeuvre envelope.



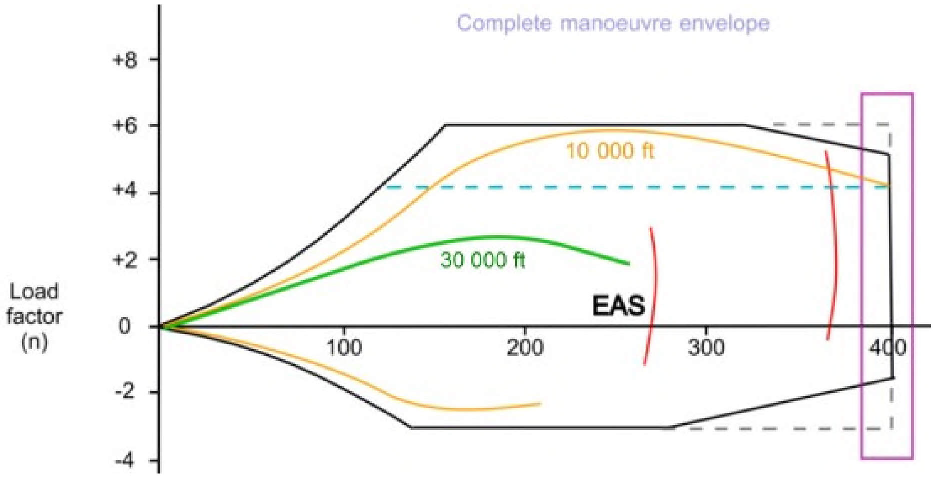


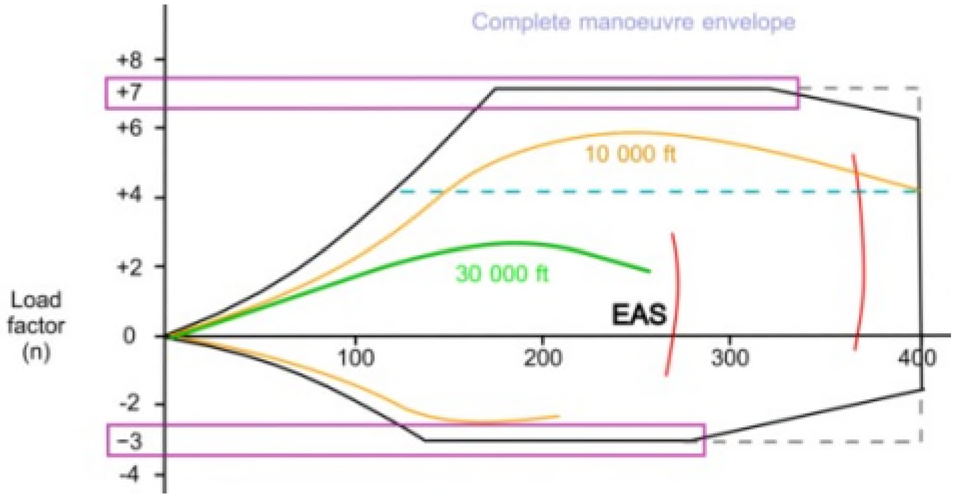
The basic manoeuvre envelope has now been modified to incorporate a large amount of extra information. The graphic on the left is how the complete envelope will look like.

INFORMATION FROM MANOEUVRE ENVELOPE

The following basic limitations can be read from the envelope:

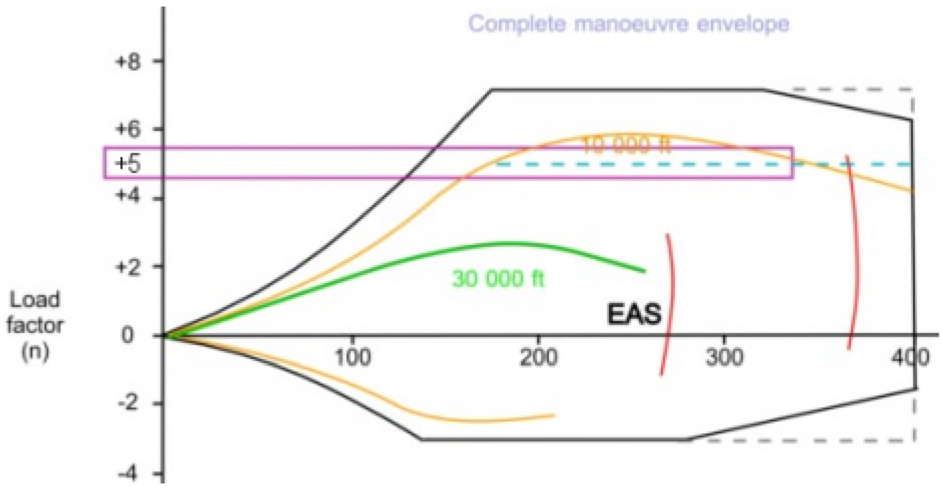
- Maximum EAS. (**400 kts**)





- Maximum permitted load factor. (**+7 and -3 g**)

- Rolling g limit. (**+5g**)

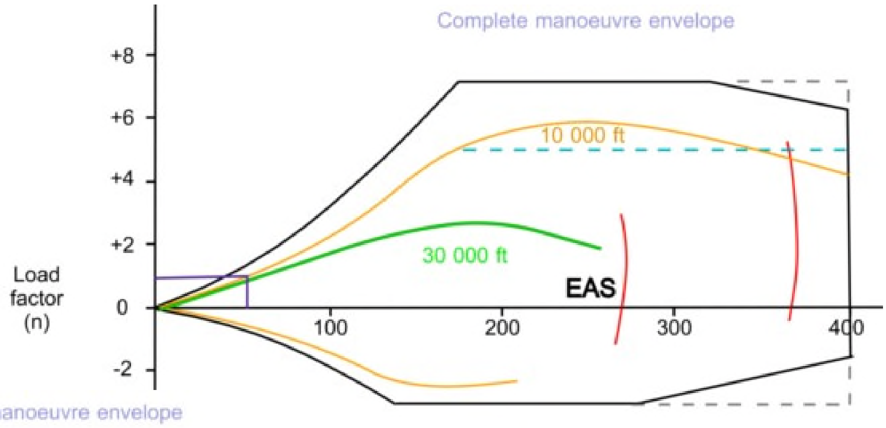


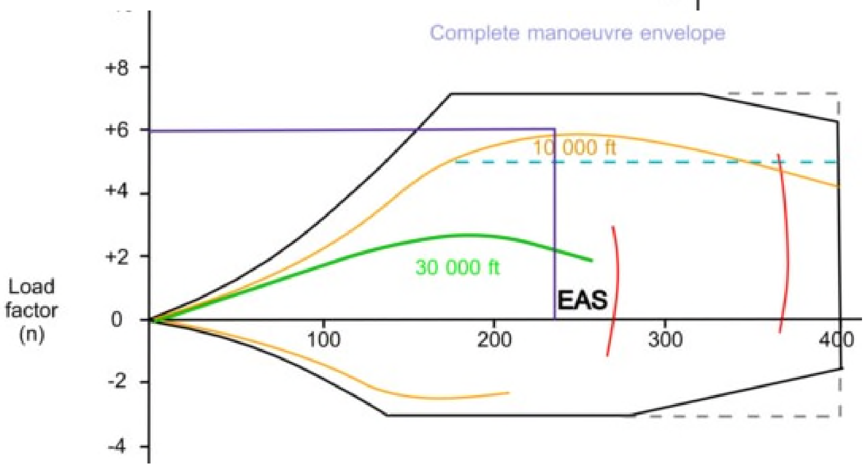
Take the following example:

The aircraft is recovering out of a dive at 6 g and 350 knots. During the recovery the aircraft is rolled into a turn while maintaining the g loading. The Rolling G limit has been exceeded.

Further information available is:

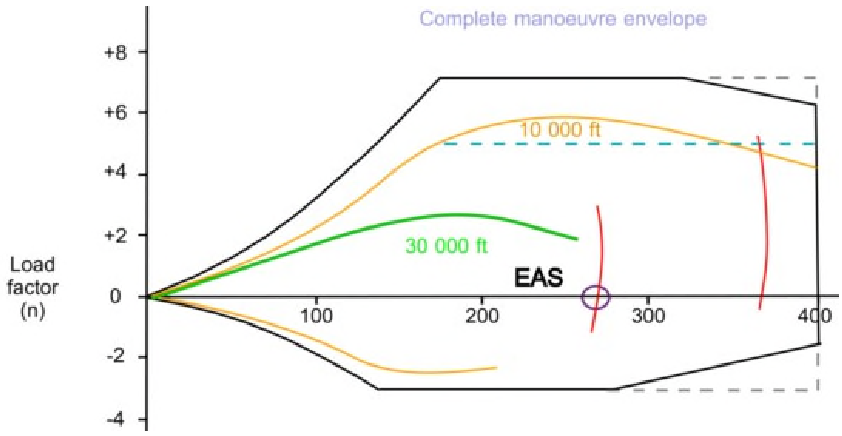
- Basic stalling speed ***(at 1 g).*** (**Approximately 55 knots**)

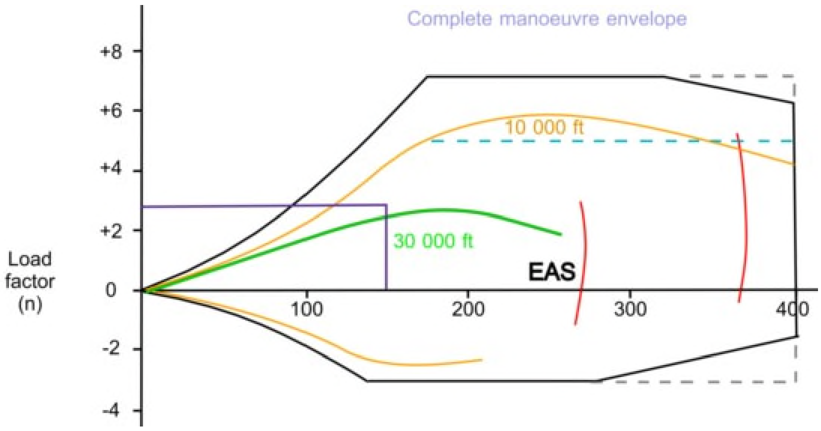




- Available load factor at any height and speed. (**eg. 240 knots at 10 000 feet gives +6 g**)

- Maximum EAS at any height. (**eg. 270 knots at 30 000 feet**)





- Stall speed at any height and load factor. (**eg. 3g at 10 000 feet gives a stall speed of 160 knots**)