Lesson Thirteen

AIRCRAFT STUCTURAL LIMITS

One of the primary instruments in the cockpit of any aeroplane is the Air Speed Indicator (ASI) which, as the name suggests informs the aviator of the speed the aeroplane 'thinks' it is going through the air (IAS). The dial of the ASI usually has colour coding throughout the speed range of the indicator. It has a green arc which extends from **Vs** to some much higher figure where it suddenly becomes a yellow (caution) arc, which then continues on to a red radial line situated toward the top of the instruments range. Inside of these two coloured arcs is a further white arc which usually extends from a speed a little below **Vs** to a somewhat higher speed. These different coloured arcs and radial lines represent some of the aeroplane's structurally significant speeds and speed ranges.

An aeroplane in flight is continually being subjected to various air loads, vibrations, gusts and manoeuvre loads. Part of the job of the designer is to design it to be strong enough to withstand these loads over and over again for many thousands of flying hours without critical parts of the structure failing. Obviously there are limits to the maximum load that any structure can withstand and these limits are clearly laid down for an aeroplane in its 'Flight Manual'. Some of them are displayed on the face of the ASI by way of the coloured arcs. Unfortunately most pilots do not fully understand these limits, nor do they understand their part in using these ASI colour codes to protect the aeroplane's structure from being 'overstressed', that is, 'Bent'! In saying this I mean no criticism of these pilots or their instructors because the definitions and the meaning of many of these limits have, over the years, become quite confusing. This is my attempt to clarify them.

Aeroplane structures are subjected to many loads that the pilot has little direct control over, such as the stress that raising and lowering the undercarriage or flaps can have on the mechanism and the various levers, bearings and bell-cranks associated with this activity. Engine vibration puts continual stress on engine mounts and airframe in addition to the internal wear within the engine. Undercarriage and flap operating speed limits and engine power setting limits are clearly laid down in the aircrafts 'Flight Manual' and should be adhered to. The **white arc** on the ASI is either the flap or the undercarriage operating speed range and the engine tachometer has similar colour coding to inform the aviator of the recommended and limiting power settings for that particular engine. These colour codes are clearly defined in the aeroplane's 'Flight Manual', so I am not going to elaborate on them any more here.

I wish to address the subject of the flight loads that the pilot puts on the aeroplane whenever he or she maneuvers it or flies it into turbulent air, as this is where the pilot's influence on the long term structural integrity of the aeroplane is greatest. The parts of the aeroplane that are most critical under stress when the aeroplane is manoeuvring or experiencing loads due to turbulence are the wings and their attachment to the fuselage. It is the wings that generate the lift and centripetal force which causes the aeroplane to manoeuvre (accelerate), which in turn causes the apparent increase in the weight of the aeroplane via the centrifugal force. As we have discussed in a previous lesson, we express this acceleration in multiples of 'G'. It is the wings and the 'G loads' they are subjected to that I wish to focus on. First, let us consider the loads caused by the intentional maneuvers performed by the pilot. I will return to the gust loads caused by turbulent air later.

The following diagram (Figure One) is a 'head on' view of a conventional aeroplane in straight and level flight. By conventional, I mean one fuselage supported by a wing sticking out each side. (There have been many deviations from this convention over the years, but 99% of the aeroplanes flying today are, in this sense, 'conventional'.)

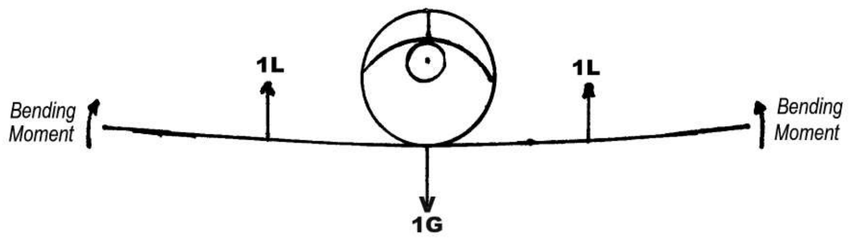

Figure One – Loads in Straight and Level Flight

The majority of the mass of a conventional aeroplane is contained within the fuselage and the 'lift', through each wing's aerodynamic centre, is outboard of the aeroplane's centre of gravity (The location of the aerodynamic centre was described in Annex C to the lesson on Stability and Control).You can see from the diagram that this means that the wings are subject to continual bending 'moments'. Now in the next diagram (Figure Two) I show the same aeroplane in a 60º bank turn, but with 'wings level' and the horizon banked for clarity. As we learned in the lesson on manoeuvring, a 60º bank turn requires twice the lifting force from the wings, and because of this, the fuselage (and everything in it) 'feels' twice as heavy (2G).

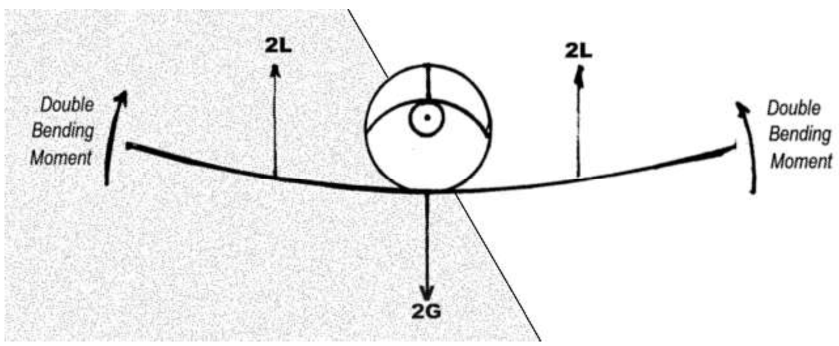

Figure Two – Loads in a 60º banked turn

It should be apparent that the bending moment on the wings is twice what it was in straight and level flight. (I have exaggerated the bending a little for emphasis in these diagrams.) Here is another at 4G, which is about the acceleration an aerobatic aeroplane would experience entering a loop (Figure Three).

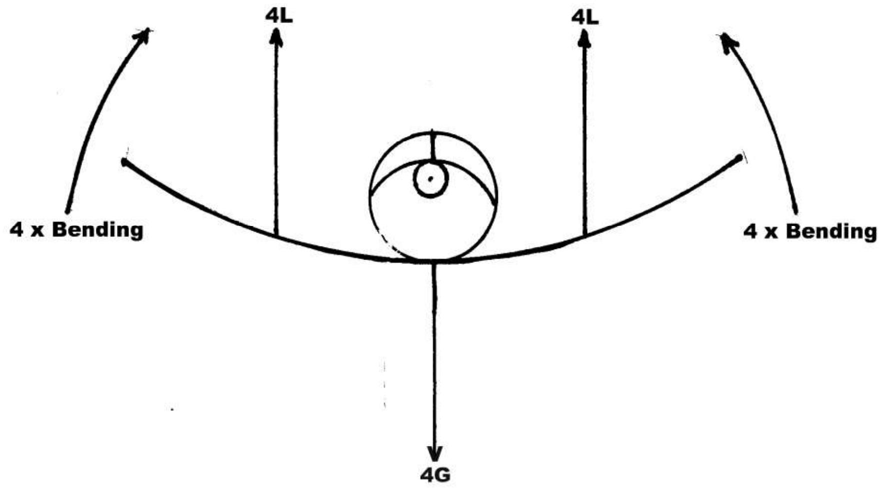

Figure Three – Loads in a 4G entry to a Loop

Since the aviator has immediate and direct control of the lift being developed by the wings, he/she also has immediate and direct control of the acceleration the aeroplane is subject to and consequently the bending moments applied to each wing. The aviator can vary the lift by varying either the aeroplanes airspeed or the angle of attack of the wings, or both. Remember, the simple expression for this is:

$$\mathbf{L \propto A/A \times V^2}$$

This means: lift varies directly with change of angle of attack and also varies with the 'square' of the change in airspeed. (This is a simplification of the standard formula for the calculation of lift, in that only those parts of the formula that the pilot has immediate control over are included. I refer you back to Annex C to the lesson on Lift.) So if we double the A/A we get double the lift, but if we double the airspeed we get **four** times the lift at the same A/A! (If you are a bit 'hazy' on this I again refer you back to the lesson on Lift.)

As I have detailed in previous lessons, the instant, equal and opposite reaction to this variable lift force is a centrifugal force, commonly (although incorrectly) expressed as a 'G force'. Designers and aviation regulatory authorities impose limits to the 'G' a particular aeroplane can be subjected to. They could equally express these limits as limits of allowable lift, because without 'lift' you can't get 'G'.

The amount of lift that can be developed by a particular wing when set at its maximum (critical) A/A will depend upon airspeed. Any attempt to get more lift at a particular airspeed by increasing the A/A further will cause the wing to stall and deliver less lift. So we can say that, in a way, the stall acts as a sort of 'safety valve' or 'safety net', which prevents too much lift and therefore too much 'G' being developed at a particular airspeed.

Remember the formula for calculating the stall speed at a particular 'G'? (From the lesson on Stalling.)

$$\mathbf{Vsm = Vs\sqrt{G}}$$

This means that the velocity of the stall in a manoeuvre (**Vsm**) equals the velocity of the stall at 1G (**Vs**), multiplied by the square root of the manoeuvring 'G', (remembering that **Vs** is the 1G stall speed at maximum 'all up' weight).

We can rearrange this formula to give us the maximum possible 'G' at any airspeed.

$$\mathbf{\sqrt{G} = Vsm \div Vs}$$

Therefore: $\mathbf{G = (Vsm \div Vs)^2}$

For example, if our aeroplane's **Vs** is 55kts and we are flying at 110kts (2Vs), we have the **potential** of 'pulling' 4G. Calculated as follows:

$$\mathbf{G = (110 \div 55)^2}$$
$$\mathbf{G = 2^2}$$
$$\mathbf{G = 4}$$

Now 4G is beyond the allowable limit of most aeroplanes, but those same aeroplanes are quite capable of flying at airspeeds greater than 2Vs. This means it is possible (if we increase the A/A to its maximum) to overstress them at cruising speed. What if we were to dive this same aeroplane to 165kts?

$$\mathbf{G = (165 \div 55)^2}$$
$$\mathbf{G = 3^2}$$
$$\mathbf{G = 9!!}$$

Now 9G is enough to do serious damage to most aeroplanes, but 165kts is only 3Vs and can easily be achieved by most aeroplanes!

Using this formula we can create a graph of the 'G' possible at the maximum angle of attack for every airspeed within the aircrafts airspeed range. Here it is at Figure Four.

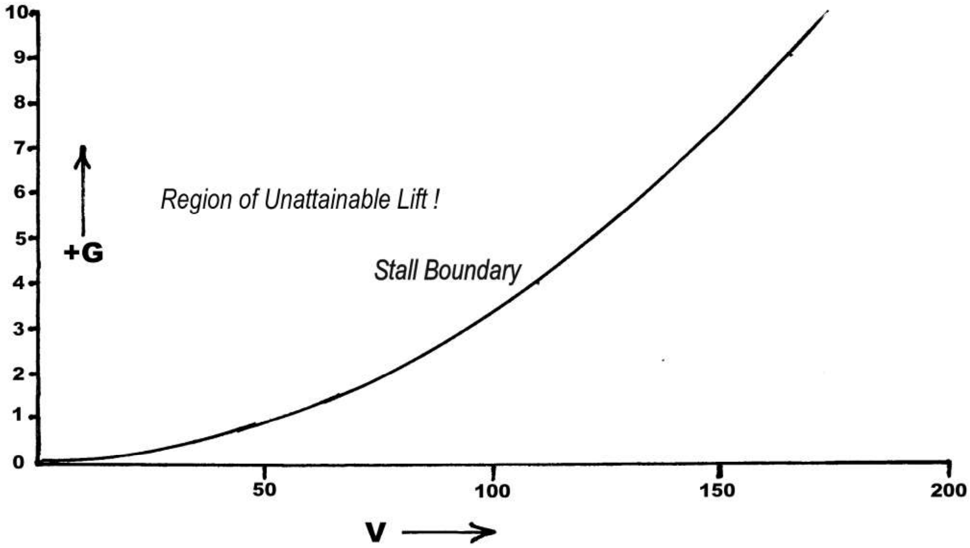

Figure Four – 'G' versus Airspeed at Maximum A/A

Note that the 'G' is increasing as the 'square' of the speed and since this line represents the 'G' which is possible at maximum (critical) angle of attack, it is not possible to 'pull' more 'G' at any particular airspeed because the wing will stall. We call this line the 'stall boundary'. So whilst we can vary the A/A and the lift in the normal way when operating below the stall boundary, we cannot increase lift or 'G', by increasing A/A when we are operating at the boundary. (The region of the chart beyond the stall boundary is often referred to as the 'Region of Unattainable Lift'.)

The designers of the aeroplane will declare a 'Design G limit' at maximum 'all up' weight, and since the aeroplane we are using in this example is an aerobatic aeroplane, its positive 'G' limit is 6. So we can add a further line to our graph showing this 6G limit (Figure Five).

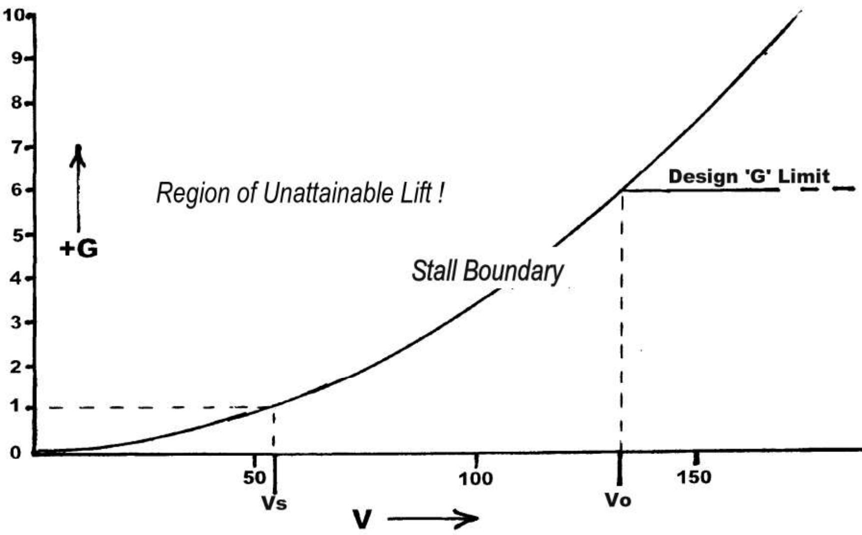

Figure Five – Design 'G' Limit and corresponding Airspeed

I have included **Vs** on this graph too, which you can see occurs at 1G. Also note that the 'Design 'G' Limit' line intersects the Stall Boundary at a particular airspeed which is given the symbol **Vo**, meaning the "**O**perating manoeuvring speed". To put it another way, **Vo** is the stall speed at the 'G' limit. **(Vo = Vsm @ 6G.)** Now, we could calculate **Vo** using the stall speed formula and inserting the limiting G into it as follows:

$$\mathbf{Vsm = Vs\sqrt{G}}$$
$$\mathbf{Vo = Vs\sqrt{G\ limit}}$$
$$\mathbf{Vo = 55\sqrt{6}}$$
$$\mathbf{Vo = 55 \times 2.45}$$
$$\mathbf{Vo = 135kts}$$

Or we could simply extract it from the graph. You can see that **Vo** on the graph is 135kts. This graph also shows us that at any speed below 135kts it is not possible to 'pull' 6G because the wing will stall and prevent it. (Here is the stall acting as a safety net.) But at speeds greater than 135kst it is possible, so the pilot has to exercise restraint in the way in which the aeroplane is maneuvered when flying faster than **Vo**.

Vo does not mean that the aeroplane cannot be maneuvered at greater speeds. It simply means that care should be exercised to ensure that the G limit is not exceeded, as the pilot is now 'working without a safety net'.

If this were a 'normal' category aeroplane, which is limited to only +3.8G, its **Vo** would be only 107kts, but the aeroplane would be capable of cruising much faster than this. Which is why all pilots, whether or not they fly aerobatic aeroplanes, **must** understand this **Vo / 'G'** Limit relationship. (Since **Vs** is the 1G stall speed at maximum all up weight, **Vo** must also be the G limit stall speed at Maximum all up weight. See annex B for further discussions on this aspect of **Vo**.)

In addition to calculating **Vo**, the designer also calculates the limit on how fast the aeroplane should be flown. He has many things to consider when determining this speed limit. One is simply the straight structural load on the airframe as a result of the drag caused by pushing it through the air at speed. Another is any control problems which may occur at speed, such as control flutter, and another, which is only applicable to fixed pitch propeller driven aeroplanes, is the speed at which the propeller will 'windmill' at 'red line' RPM with the throttle closed. This figure is given the symbol **Vd**, the 'design **d**ive speed', but you won't find it on the ASI because the regulators have introduced a 'safety buffer' by defining another speed equal to **.9Vd** which is given the symbol **Vne**, which stands for "**V**elocity **n**ever **e**xceed" and this figure is represented on the ASI by the **red radial line** near the top of its speed range. **Vne** can now be added to our graph as a vertical line extending from this speed (Figure Six).

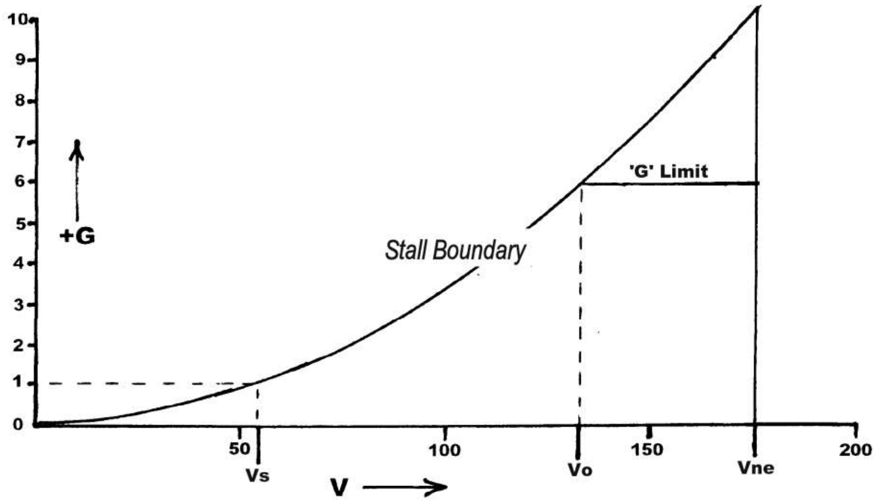

Figure Six – Velocity Never Exceed

The **Vne** in this example has been set at 175kts. You can see that there is an area of the graph at speeds between **Vo** and **Vne,** and above the ‘G’ limit line, where the pilot has the ‘potential’ to overstress the aeroplane. Indeed at **Vne** the potential is 10G!

So far we have been assuming that all the accelerations have been positive, that is, positive ‘G’, but in turbulence and certainly with aerobatic aeroplanes negative accelerations can also be experienced. Most aeroplanes are not designed to be as strong under negative accelerations, so whilst the negative ‘G’ side of the graph is similar to the positive ‘G’ side, the negative ‘G’ Limit and negative **Vo** will be different. Here is the complete graph incorporating both positive and negative ‘G’ limits for an aerobatic category aeroplane with a +6 and -3 ‘G’ limit (Figure Seven).

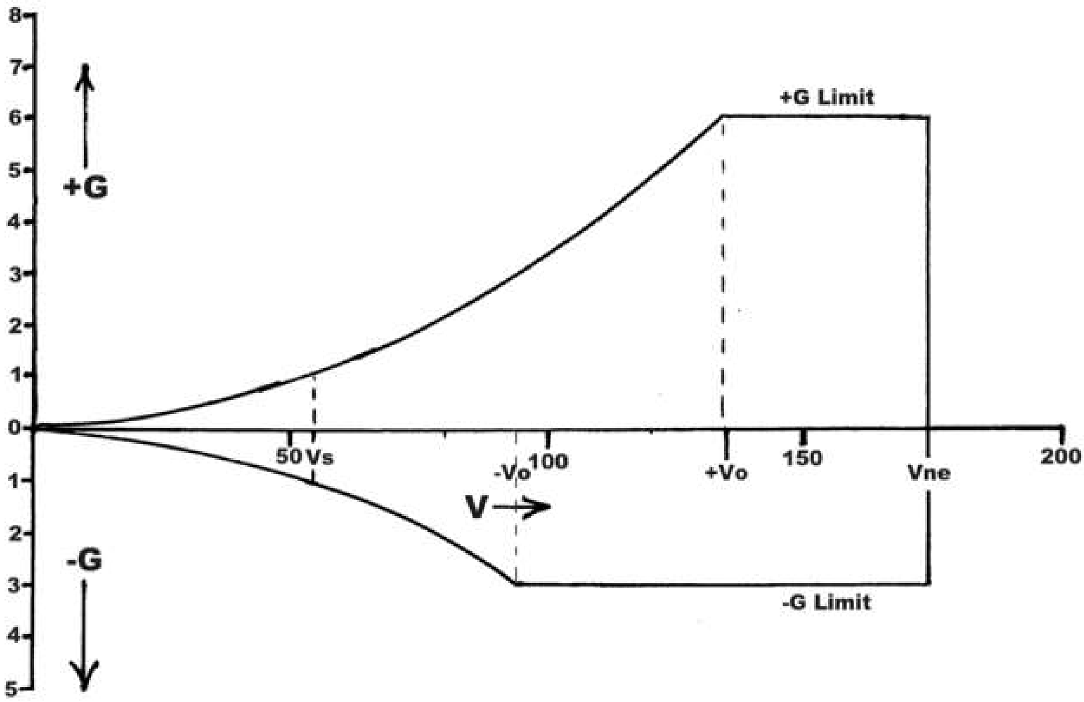

Figure Seven – Negative ‘G’ Limits

So we now have a graph which defines all of the structural limits of the aeroplane, (well almost). The curved lines represent the ‘stall boundary’ and the ‘G’ beyond this line is ‘unattainable’ because the wings will stall at the boundary, whilst the horizontal lines represent the acceleration limits imposed by the designer (or regulator), on any pitching manoeuvre the aviator might attempt when flying at speeds above **±Vo**, and the vertical line represents the airspeed limit beyond which the aeroplane should not be flown. These lines enclose an area which is called the aeroplane’s ‘Manoeuvre Envelope’. Flight within this envelope is okay but flight outside it is either impossible or damaging to the aeroplane. All aeroplanes, regardless of the purpose for which they are designed, have Manoeuvre Envelopes similar to this, but the +/- acceleration limits and **Vs, Vo** and **Vne** will, of course, vary with each type.

Accelerometers, in those aeroplanes fitted with them, usually have the +/- acceleration limits marked on them with red radial lines to assist the aviator in determining his proximity to his aeroplane’s ‘G’ limit when manoeuvring. These limits will depend upon the category of operation. I cannot emphasize enough how important I believe it is that an aviator understand the Manoeuvre Envelope of his/her aeroplane.

Is there anything more to learn about the Manoeuvre Envelope? Yes there is. Let’s step back and take another look at our aeroplane head on (Figure Eight).

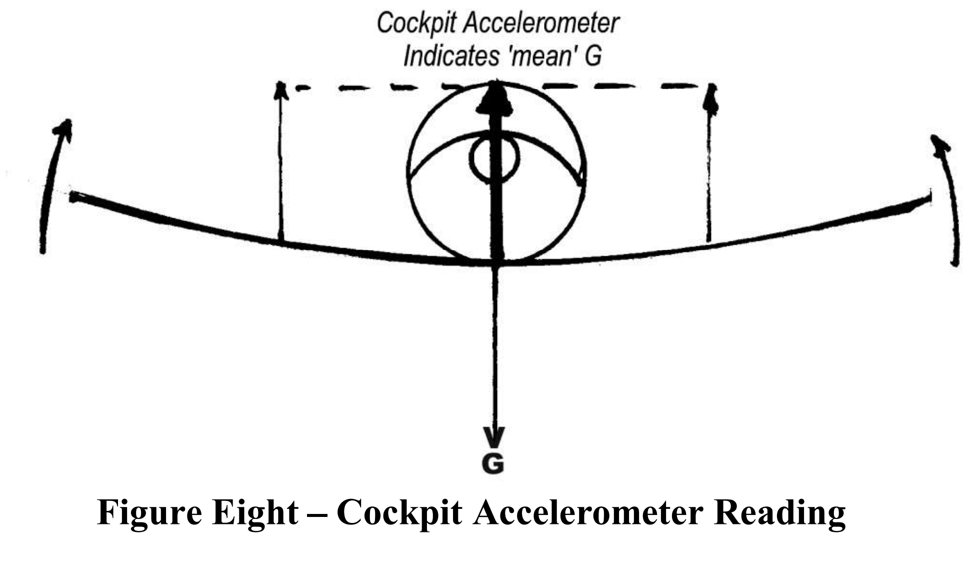

Figure Eight – Cockpit Accelerometer Reading

Each wing produces its ‘share’ of the required lift, and its ‘centre of lift’ vector is located at the aerodynamic centre of the wing, but the accelerometer is mounted in the cockpit and will be indicating the mean lift/G being experienced. If the aeroplane happens to be rolling, then one wing must be developing more lift than the other, but because the accelerometer is in the centre of the aeroplane it will only indicate the mean of these two lift forces, and this could be unchanged from straight and level flight despite the fact that the ‘up going’ wing is obviously being stressed to a greater degree than the ‘down going’ wing (Figure Nine).

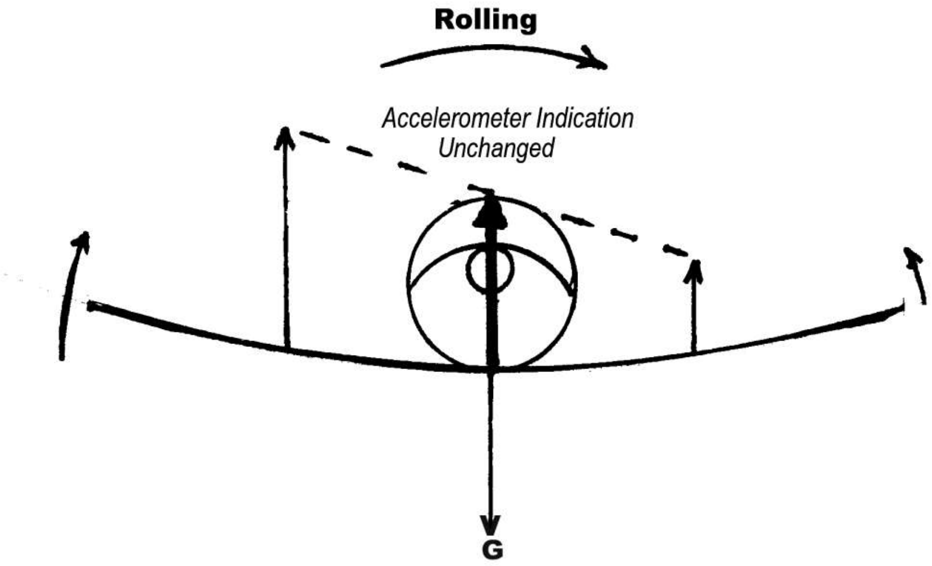

Figure Nine – Cockpit Accelerometer Reading during a Roll

Now the act of rolling the aeroplane in straight and level flight is not going to generate sufficient asymmetric lift to exceed the aircraft's design limits on either wing, but what if the pilot rolls whilst doing a high 'G' manoeuvre? Imagine that the following head on view is of an aeroplane that is just arriving back in level flight after doing a loop. The pilot has not yet relaxed the A/A but at this instant he/she rolls the aeroplane at maximum rate (full aileron deflection). Figure Ten.

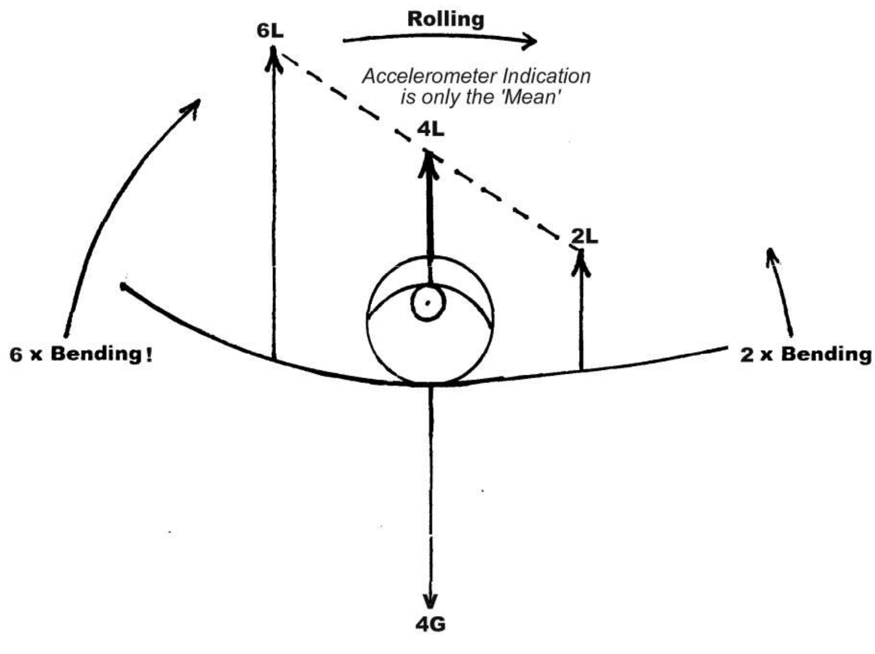

Figure Ten – Rolling whilst 'Pulling' 4G

The symmetrical lift generated toward the conclusion of the loop causes an acceleration of 4G, and is indicated on the accelerometer, but then the rapid roll is caused by an <u>additional</u> asymmetric lift. The 'up going' wing is now generating 6L, whilst on the 'down going' wing only 2L, but the mean indicated

on the accelerometer is still 4L (4G). Here we have a situation where the 'up going' wing is at its acceleration limit but the accelerometer is not showing it!
If we view the same situation from the side (Figure Eleven) you can see that the 'up going' wingtip is flying along a much tighter curve than the fuselage, and the tighter the curve (at a particular airspeed) the more the 'G'. Conversely, the 'down going' wing is flying along a more 'relaxed' curve and is being subjected to less 'G'.

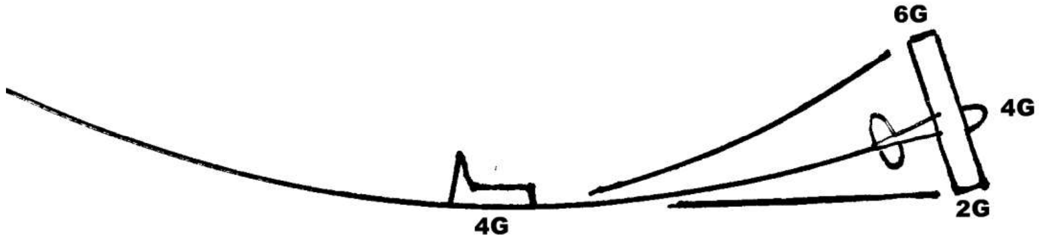

Figure Eleven – Side View of a 'Rolling G' Manoeuvre

Now imagine that we are manoeuvring the aeroplane at an indicated 5G and rolling at maximum rate. We have just overstressed the up going wing without the situation being recorded by the accelerometer! (Accelerometers usually have 'tell-tale' hands which remain at the maximum and minimum accelerations achieved on a particular flight.) If we could install remote reading accelerometers feeding acceleration data to us from each wingtip in addition to the one already in the cockpit, we could see what was going on, but I don't know of any production aeroplane that has such an accelerometer set up.

So what can the aviator do to avoid inadvertently over stressing the 'up going' wing during a 'rolling G' manoeuvre? Obviously if the intention is to roll at maximum rate the 'G' being pulled (or pushed) at the time must be limited to something less than the usual limit for that aeroplane. A 'rule of thumb' in common use by those aviators that understand the problem (and, now, this includes **you**) is to limit the 'G' as seen on the cockpit accelerometer, whilst rolling at maximum rate, to **2/3** of the design limit. That is:

Rolling 'G' limit = 2/3 Symmetrical 'G' limit.

So an aerobatic aeroplane limited to +6 symmetrical 'G', would have a 'rolling G limit' of +4, whilst a normal category aeroplane limited to +3.8 symmetrical 'G' would have a 'rolling G limit' of only +2.5 and both would have a corresponding **Vo(rolling)** calculated as follows:

Rolling 'G' = 2/3 x 6 = 4G

So, inserting **4** into the 'stall boundary' formula we get:

$$\textbf{Vo(rolling)} = \mathbf{Vs\sqrt{4}} \\ = \mathbf{55 \times 2} \\ = \mathbf{110kts}.$$

This means that the aeroplane in our example will stall under +4G at 110kts and this will prevent a 'rolling G' overstress in the same way that a stall at **Vo** will prevent a 'symmetrical G' overstress.

Can the aeroplane be rolled at all above +4G? Yes it can, indeed at +4G it can be rolled at maximum rate but the roll rate must be progressively reduced as the 'G' gets greater until at +6G it should not be rolled at all. If in doubt relax the 'G' to +4 or less before rolling. Now this is not too difficult in an aerobatic aeroplane because we are dealing with high acceleration limits, but in a normal category aeroplane where the 'rolling G' limits are quite low, and the aeroplane is cruising at speeds well in excess of **Vo(rolling)**, caution must be exercised in the manner in which the aeroplane is maneuvered or damage could result.

The following Manoeuvre Envelope diagram (Figure Twelve) includes (+/-) 'rolling G limit' lines and shows the speed at **±Vo(rolling)**, which for brevity I have labeled **±Vr**. (My use of the symbol **Vr** in this context is not a standard abbreviation.)

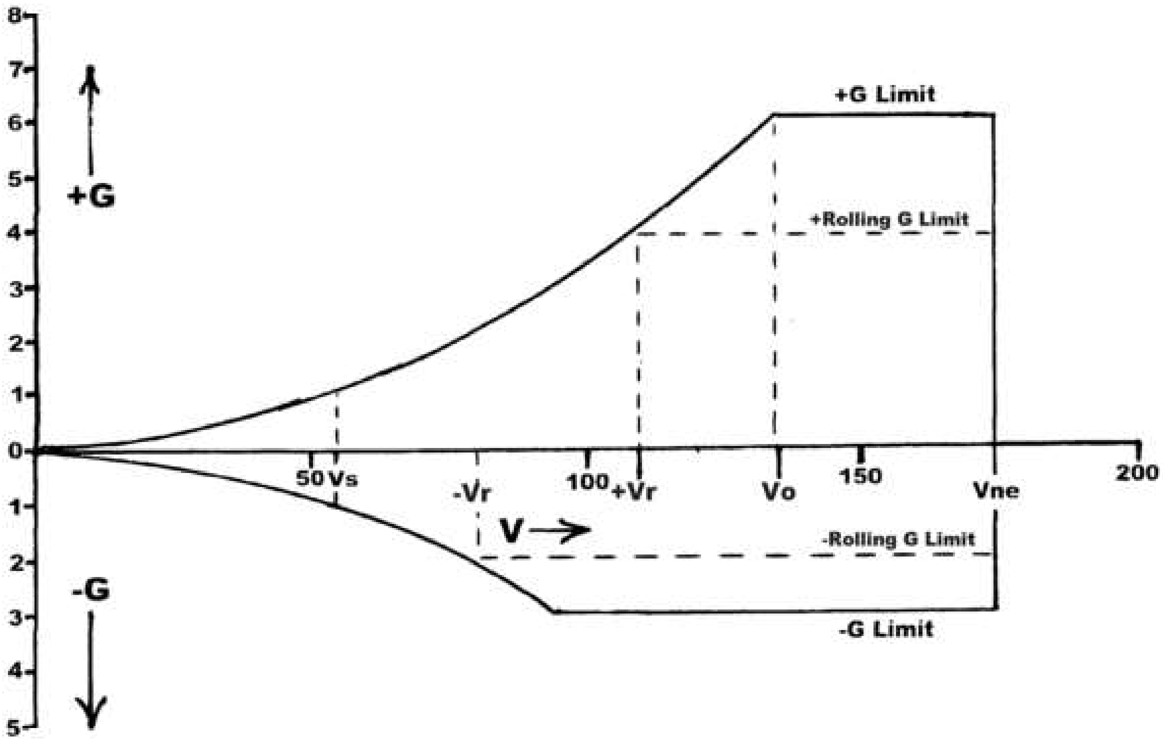

Figure Twelve – Manoeuvre Envelope including Rolling G Limits

'Rolling G' and its limiting effects on an aeroplane's safe manoeuvre envelope is one of the least understood aspects of aircraft structural limits. Many, many aeroplanes have, over the years, been seriously overstressed and damaged as a direct result of this ignorance. But now that you are aware of this, for you, ignorance is no longer an excuse.

In Annex D to the lesson on Manoeuvring I detailed the phases of a spiral dive and labeled the third phase the 'structural limit phase'. The structural limits referred to are the 'rolling G' limits of the aeroplane because in a spiral dive the aeroplane is both rolling and pitching simultaneously and, as the speed builds up, so does the rolling G! The limiting speed in a spiral dive would therefore be **Vo(rolling).**

At Annex C to this lesson I have included a table which shows the symmetrical and rolling 'G' limits for the three standard operational categories of civilian aeroplanes and their associated **±Vo** and **±Vo(rolling)** factors. All you have to do is insert the **Vs** of your aeroplane into the formulas provided, to calculate the corresponding structural airspeed limits for the aeroplane.

Quite often you will find manoeuvre envelope diagrams which have the right hand corners cut off like the one shown in Figure Thirteen. This is because certain gust response criteria have been superimposed onto the manoeuvre envelope.

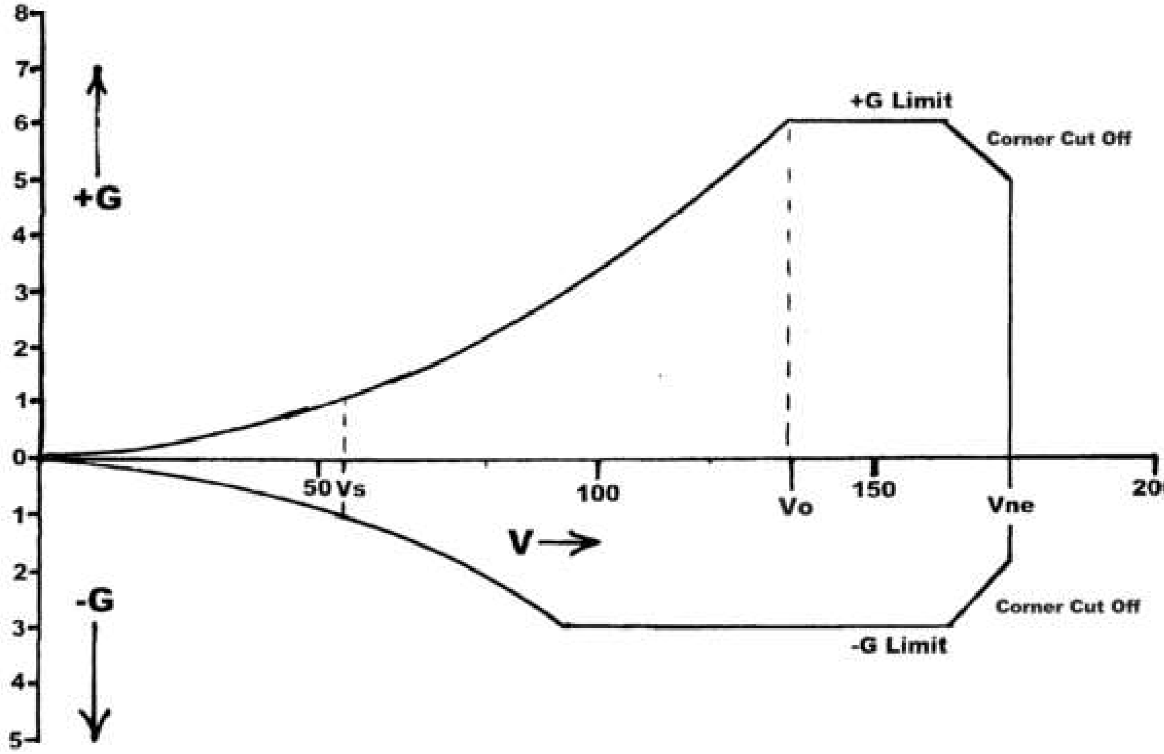

Figure Thirteen – Manoeuvre Envelope minus the corners

These missing corners mean that at speeds approaching **Vne** the G limit reduces progressively. This modification is quite common on the Manoeuvre Envelopes of normal category aeroplanes. Because these diagrams contain not only manoeuvre data but also gust response data, they are called 'Flight Envelopes'. You will find a full explanation for these missing corners in Annex A.

This leads us onto the second part of this lesson which is about flight in turbulent air. Turbulent air currents can be experienced on windy days on the lee side of hills and mountains, in or near cumulus type clouds (especially thunderstorms), at high altitudes near jet-streams, and on hot days with strong 'thermal' activity, or in 'bad weather' in general. Turbulence can consist of horizontal or vertical gusts (or both simultaneously) of varying strength. Horizontal gusts produce momentary changes in the aircrafts airspeed or balance due to its inertia but only small and relatively unimportant changes in the flight load factor, however, vertical gusts can have severe effects on the aircraft's structural integrity and that is what concerns us here.

Vertical gusts can momentarily alter the angle of attack of the wing, which alters the lift being generated by the wing. This excess lift then causes unwanted acceleration. The following diagram shows how this change of angle of attack comes about (Figure Fourteen).

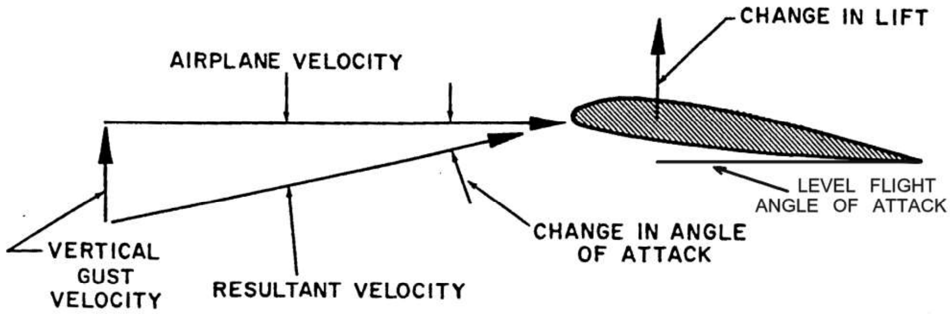

Figure Fourteen – Gust related change of A/A

As you can see, at a given airspeed the angle of attack changes with the strength of the gust. In severe turbulence the increased lift and therefore the acceleration produced, can exceed the design limit. So in severe turbulence the airspeed should be reduced to a figure that prevents the aeroplane from being over stressed by allowing the stall to act as a safety net. This speed is called the 'Turbulence Penetration Speed' and is given the symbol **Vb**. It should come as no surprise to you to learn that **Vb** equals **Vo!**

What size vertical gust would be required to cause the angle of attack to increase to the critical angle at **Vb**? Well, assuming that the critical A/A of the wing of our aerobatic aeroplane is 16º and it is flying level at 2.5º A/A, at 135kts (Vb), the A/A would have to increase a further 13.5º. The following triangle of velocities shows the gust which would be needed (Figure Fifteen).

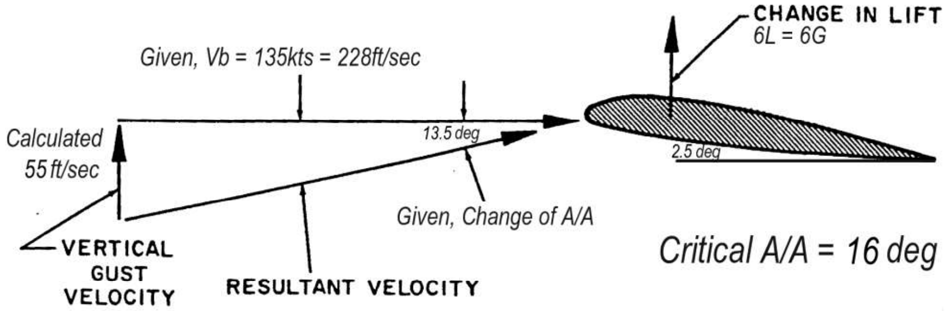

Figure Fifteen – Vertical Gust required to produce Critical A/A

You can see that the vertical gust speed would be 55ft/sec, which is 3300 feet/minute or 32.5kts! Flight in conditions which produce such gusts would be a ‘wild ride’, and can be experienced inside a thunderstorm if you are foolish enough to go there.

What would the acceleration be, at **Vb,** if only a 50ft/sec gust was encountered? It would be 5.45G (6 x 50/55). So the aeroplane could go faster before a 50ft/sec gust would produce 6G. This is because the A/A required to maintain level flight (1G) reduces as the square of the increased airspeed and we only need 6 times that reduced A/A to produce 6G. (If this is a little difficult to grasp refer to Annex A for more detail.)

Regulatory authorities impose ‘gust response’ criteria upon the designs of aeroplanes, which means the designers have to work the problem backwards from the way that we have been looking at it. That is, they start with a particular vertical gust speed that the aeroplane has to be able to withstand and work backward to find the maximum speed at which the aeroplane can be flown in such a gust without the G limit being exceeded. The mathematics for calculating this speed are a bit more complicated as there are a couple of variables involved, so we are not going to go into them in great detail here, (but I have in Annex A if you are interested). However, just to give you a feel of what I am talking about, consider our aeroplane flying level but faster than in the previous example. As a result its A/A has reduced to 2.2º. Ask yourself how much would this A/A have to increase to produce 6G? The answer of course is 6 times, which is an increase of 11º, for a total of 13.2º (2.2º x 6). So if I told you that the gust response criterion was 50ft/sec, some simple trigonometry would give you the corresponding airspeed at which this 11º increase in A/A would occur (Figure Sixteen)

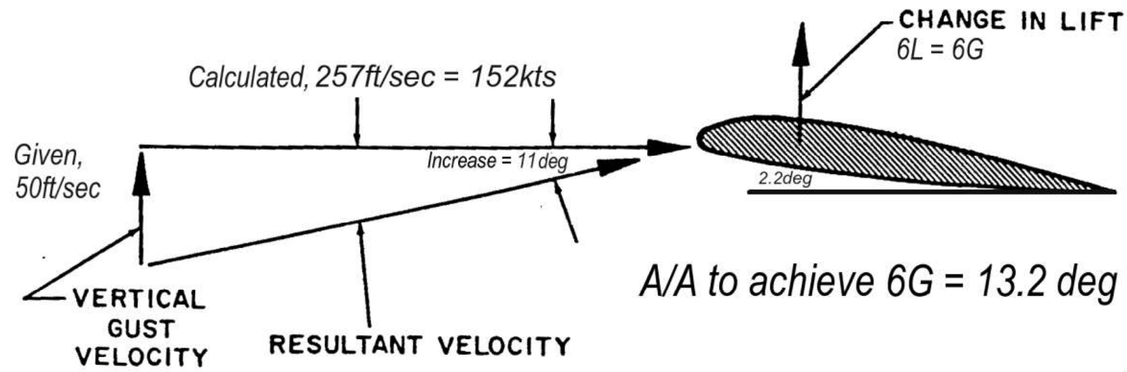

Figure Sixteen – Airspeed Limit for 50ft/sec Vertical Gust

You can see that in this example the answer is 257 ft/sec which is 152kt. Now this speed is above **Vb** so a stronger gust (say 55ft/sec) has the potential to overstress the aeroplane. However, the ‘regulatory authorities’ have concluded that a 50ft/sec gust would only be exceeded in the most extreme circumstances so the associated airspeed is, therefore, safe under all but extreme conditions.

If you are finding this concept difficult to follow lets look at it another way. Imagine the pilot of our aeroplane (working without a safety net) at 152kts pulls 6G. To do that he would have increased the A/A to only 13.2º, which is all that a 50ft/sec gust could produce at that speed. The pilot chooses not to pull more than 6G, whilst the gust is incapable of 'pulling' more. It is the designer's job to figure out at what airspeed the 50ft/sec gust can only 'pull' 6G. His mathematics is, as I have said, a little more complex than I have used in this example but the concept is the same. (Once again I refer you to Annex A for a more detailed explanation of gust response calculation for those of you who are mathematically inclined.)

This new 'acceptable' gust response speed is called the 'Maximum Structural Cruise Speed' and is given the symbol **Vno** (**V**elocity **n**ormal **o**perating) and is the speed indicated on the airspeed indicator by the **'top' end of the green arc**. Operations beyond this speed will fall into the **yellow (caution) arc** and should only be conducted in smooth air.

Previously I said that a normal category aeroplane is capable of cruising at speeds above **Vo (Vb),** suggesting that the aeroplane could be easily and unwittingly over stressed, which it can. However, if we accept that the gust factor upon which it is predicated is reasonable and that the pilot is not going to attempt any high G manoeuvres, the concept of **Vno** makes this cruising speed more 'structurally' acceptable.

Unfortunately most pilots do not fully understand the meaning of **Vno**. They do not understand that it is a 'response speed' to a particular size gust, not a manoeuvring speed, so some may indulge in maneuvers the aeroplane was never designed to do at this speed, thinking "I am in the green arc, so it is OK"!!

We have now established that the standard markings on an Airspeed Indicator are: a green band from **Vs** to **Vno**, a yellow ('caution') band from **Vno** to **Vne** and a red radial line at **Vne**. Unfortunately **Vo** and **Vb** are <u>not</u> marked on an ASI.

I do not believe that marking **Vno** on the airspeed indicator is as much use as the 'authorities' think it is. I believe that the 'top of the green arc' should be **Vo**, as the only sure solution to a close encounter with severe turbulence is to slow down to **Vo** (or even **Vo(rolling),** see Annex B) and it is a much more useful speed to have clearly marked on the ASI when we are doing some 'serious' manoeuvring.

From what I have explained to you in this lesson, and given the correct instrumentation (shown in Figure Seventeen which follows), you should now be able to look at the indications of the accelerometer and the ASI at any time during flight and visualize exactly where you are within your aeroplane's

Manoeuvre Envelope, and fly accordingly. (Note that the accelerometer's 'at rest' indication is +1G in response to the ever present acceleration due to gravity.)

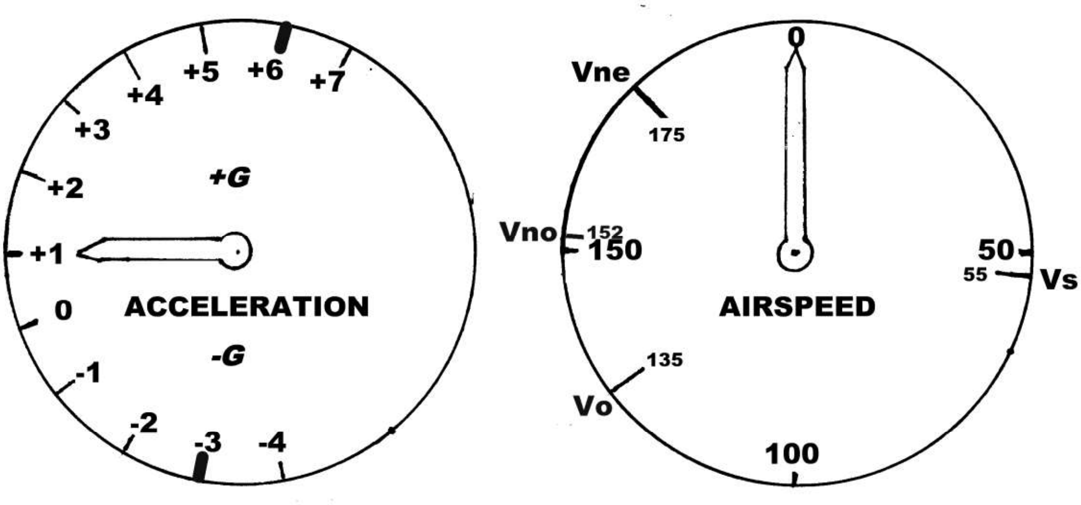

Figure Seventeen – Instrumentation needed in ALL aeroplanes

Unfortunately, you will rarely find an accelerometer in a normal category 'touring' aeroplane (I believe that all aeroplanes should have accelerometers fitted to them) and since **Vo** is not commonly marked on airspeed indicators either, the average pilot is presented with limited information about where the aeroplane is within the manoeuvre envelope when in flight, so be careful and good luck!

List of Annexes to the lesson on: Aircraft Structural Limits

Annex A. The Derivation of Vno

Annex B. More on Vo, Va and Vno

Annex C. Aircraft Structural Limits Tabulation