Aircraft Have Limits

Just because you have 'slipped the surly bonds of earth', does not mean you can ignore the sage advice of the Starship Enterprise's Chief Engineer Scotty when he says, "I cannae change the laws of physics Captain." No one can.

Whatever you are flying – a hang glider, a paraglider, a glider, a microlight, a helicopter, or an airliner – you must know the limits of your aircraft. When combined with a sound knowledge of the way forces act on your aircraft, you should be able to operate within your aircraft limits at all times.

Principles of Flight

Any time an aircraft is airborne, it is subject to at least three forces: lift, drag, and weight. An aircraft under power will also be subject to thrust. In stable level flight, these will be balanced, which also includes any tailplane force required to balance pitching moments. Lift will be equal to the aircraft weight, plus or minus (normally plus) the tailplane force. This tailplane force is normally much less than the lift force, so the lift and weight can be considered equal. *(Fig 1)*

The Four Forces

The heavier the aircraft, the more lift required to maintain level flight.

The heavier the aircraft the greater the load imposed on the airframe.

The extra lift required at heavier weights means that more drag will also be generated. So the heavier the aircraft gets, the faster it tends to slow down. This may be your only direct indication of increased loading.

A heavier aircraft flying in turbulence will also tend to ride better, since it will respond less to a given gust, again giving the impression of a smoother ride and less stress to the airframe. This is quite wrong. While the response to turbulence is reduced, the actual loads on the airframe will increase. Compare an empty trailer to one full of sand, going over pot holes. The full trailer bounces a lot less but is subject to much more loading.

Load Factor and G Limits

The ratio of lift produced to aircraft weight is called the load factor, and it is a measure of the acceleration in the direction of the manoeuvre.

$$\frac{L}{W} = LF$$

The pilot perceives this load factor as the G-force experienced.

In a 60-degree turn, the lift is twice the weight, making the load factor 2, or 2 G.

$$\frac{2}{1} = 2$$

All aircraft have load-factor limits, both positive and negative, with the negative limits generally being around half the positive limits.

These limits are found in the Aircraft Flight Manual and relate to the aircraft at its maximum all up weight (MAUW). You can fly at the 'limit load' without any resultant deformation of the aircraft. Beyond this – normally another 50 percent – is the 'ultimate load', at which point the aircraft structure has been calculated to fail. Between the limit load and ultimate load, some deformation or damage to the aircraft can be expected. The 'buffer' is there to allow for miscalculations by designers, manufacturing defects, and ageing aircraft – not for pilots to help themselves to.

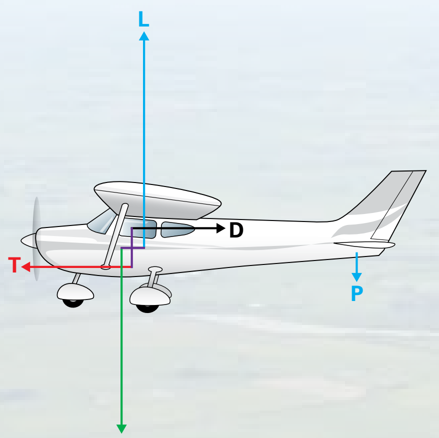

Fig 1

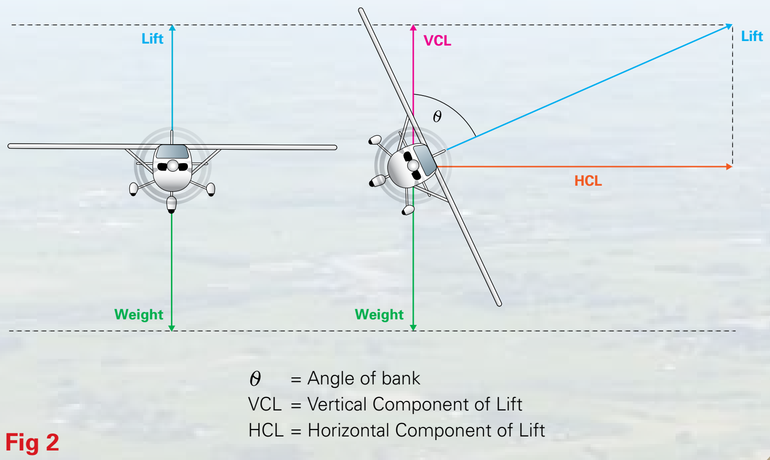

Fig 2

Turning

Whenever the aircraft is manoeuvred, the lift required changes.

As we said above, an aircraft in a 60-degree angle of bank turn experiences a load factor of 2. Effectively your aircraft (and everything in it) now weighs twice its original weight. *(Fig 2)*

In order for the wings to provide that additional lift, the angle of attack is increased, and an increased angle of attack results in increased drag (induced drag increases by about 300 percent in this situation) and a reduced airspeed (unless you add power).

With weight effectively increased in the turn, the stall speed increases (because stall speed increases with increasing weight).

In addition, when aileron is applied to roll the aircraft, the up-going wing is producing more lift than the down-going wing. It is therefore possible to exceed the design strength of the up-going wing while still below the overall aircraft limits. This can be achieved by applying aileron when G is already applied – known as 'rolling G' – or in some cases simply by applying aileron at high speed. Be cautious about application of aileron whenever under G or at high speeds.

When the aircraft is turning, you are increasing the stress on the airframe. Turbulence increases that stress even further, so rolling the aircraft into a steep turn while yanking back on the control column may just rip its wings off. *(Fig 3)*

Photo courtesy of Ross Gray

Know Your Limits

Some microlights and some amateur-built aircraft have very little information available on their speed and G-limits. It is up to you to know these limits and there are a couple of ways you can find them if they are not included in the operating manual. You might like to try the designer's web site. Alternatively you could contact the designer directly. Another option is to contact your national organisation, such as the SAA or Part 149 organisation.

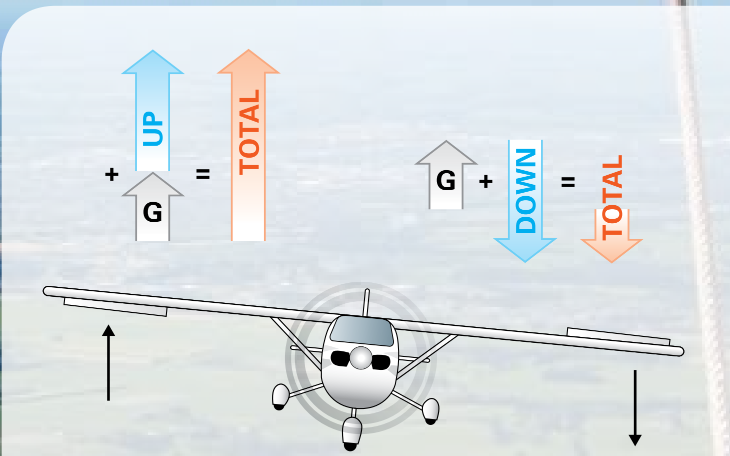

Fig 3

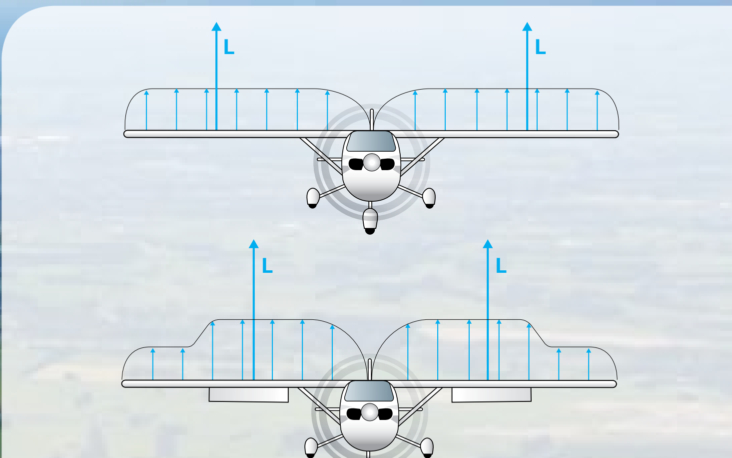

Fig 4

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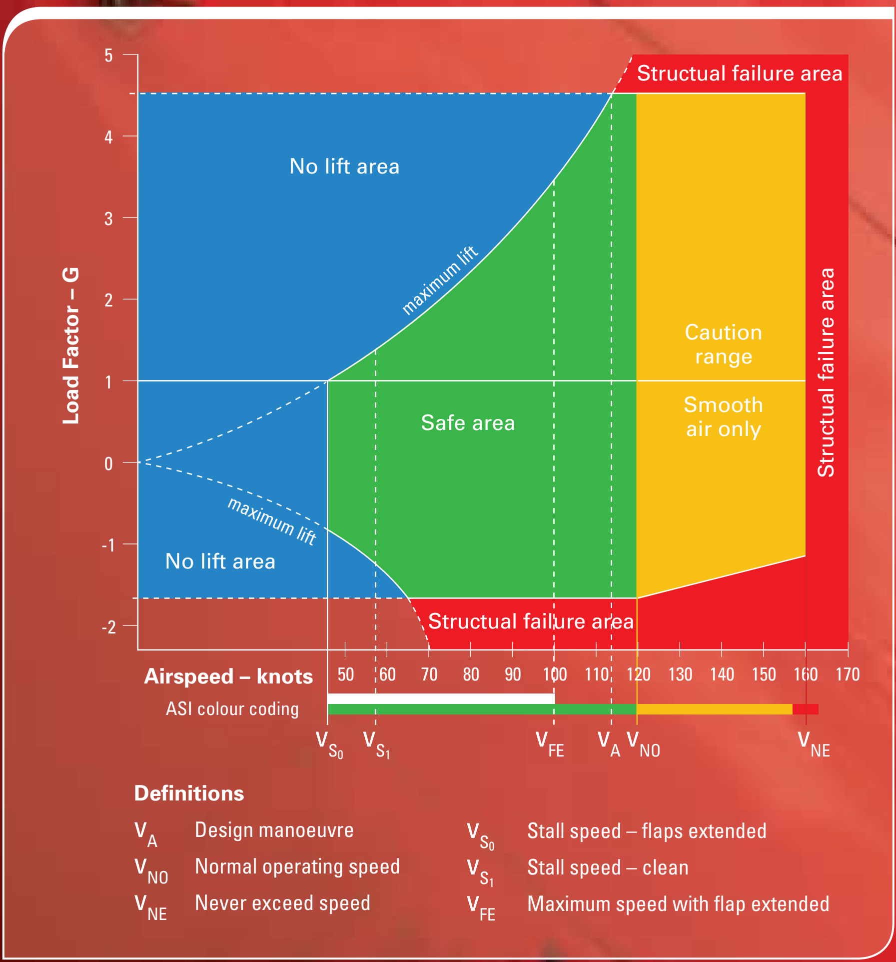
The Manoeuvre Envelope (V_N diagram)

A simple way of presenting this data is by using the V_N diagram. This is a graph of G against speed. Together, speed and G limits provide the 'flight envelope' of the aircraft: what it is allowed to do, what it cannot physically do, and what it should not do. Anything outside the envelope is beyond the limit load the airframe was designed for.



Blue Area

The blue area represents a combination of speed and G that the aircraft is physically incapable of reaching. The aircraft will stall before enough lift can be generated to produce the G force that can damage the airframe.

The curved lines between the blue area and the other areas are the stall lines, for both normal and inverted flight.

Green Area

The green area shows the speed and G combinations where there is no aero-dynamic restriction on aircraft operation. But there may be other limits, such as flap, gear limiting speeds or G. Refer to the Aircraft Flight Manual for details.

Yellow Area

The yellow area depicts speed and G combinations where there is some limit on the airframe. These are often related to use of aileron.

Red Area

The red area is a no-go, in which you are likely to cause damage, either through too much G or from the drag forces produced at excessive speed.

Manoeuvring Speed (V_A)

Practically, V_A is the maximum speed you can fly and not overstress the aircraft, as the wings will stall before you can pull enough G. When the manufacturers determine a value for V_A, they are not worried about breaking the wing, but are worried about breaking *other* important parts of the aircraft, such as the engine mounts.

Some caution is required with this speed because it is set for the MAUW of the aircraft. At weights below this, the aircraft can generate more G at a given speed. This means that the V_A reduces as weight decreases, making it easier to inadvertently overstress the aircraft. Check the Aircraft Flight Manual for the V_A speeds at lighter weights.

In turbulence, particularly when in a descent, speed control is critical to ensure V_A is not exceeded – thereby threatening structural integrity. Even in smooth air when descending from above terrain, awareness of potential turbulence, such as passing in the lee of a high mountain or range, requires anticipation of appropriate speed control.

With moderate to severe turbulence, maintain a speed below V_A.

Be cautious about elevator inputs when operating beyond V_A.

Tied-in with manoeuvring speed is the concept of 'normal operating speed' (V_{NO}), the speed that should only be exceeded in smooth air. Beyond V_{NO}, loads imposed by turbulence may overstress the airframe.

V_A reduces as weight decreases.

Flap

Lift distribution changes when flaps are deployed. Flaps cause more lift to be generated, and therefore increase the wing-bending forces. Excessive lift generation or high speed can overload the flaps and their attachment points to the wings. Aircraft therefore have lower limits for both G and speed when flap is deployed. *(Fig 4 on page 9)*

High Speeds

As speed increases, drag increases in a squared relationship – double the speed equals four times the drag. Go fast enough, and these drag forces may be sufficient to damage the airframe. All aircraft have a 'never exceed speed' (V_{NE}) above which some damage can be expected.

Changing speed also changes the lift distribution over the wings and tailplane. To produce the required lift at higher speeds requires less angle of attack, maybe only a few degrees. But most wings are designed with 'washout' or reduced incidence at the wingtips, to enhance stall characteristics. This can lead to the outer sections of the wing producing little or even negative lift. This changes the wing bending forces and at high speeds wing bending limits can be exceeded.

Flutter

Flutter is the term given to a flexing or vibration of part of the airframe due to higher-than-normal speeds. Ailerons and outer wing sections are most susceptible, particularly on aircraft with high aspect ratio wings and reduced torsional stiffness, such as gliders and some amateur-built aircraft. Once started, flutter can self-excite causing significant damage.

Fatigue

Fatigue is cumulative damage to the aircraft structure caused by repetitive loads that, by themselves, do not exceed limits, but over a period of time add up. Take a paperclip and bend it. One cycle of bending won't break it, but do it enough times and it will fail. Fatigue is generated every time the wing is loaded – even a takeoff generates fatigue. Higher loads and a higher cycle rate hasten the process. Excessive repetitive G-loading, or flying in turbulence, all adds up.

Material Specs

If you are approved to work on your aircraft, then it is your responsibility to keep your aircraft in an airworthy state. Particularly, this includes using appropriate parts – especially if those parts contribute to its strength.

If the critical parts of your aircraft are not made of the correct materials, then you are eroding the safety margins designed into your aircraft – especially if you are unwittingly overloading it. ■