

Pushing the Envelope

We all know the term “Flight Envelope”, but what is it? Gung-Ho pilots in films talk about “pushing the envelope”, qualified test pilots carefully “explore the envelope” and the rest of us, if we wish to live long and uneventful lives stay well “within the envelope”.

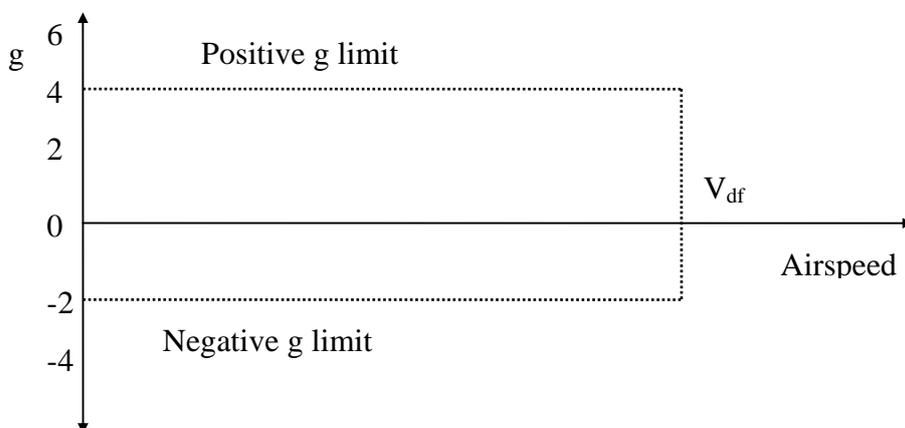
The flight envelope is the range of speeds and g-levels at which your airplane has been shown safe to operate and within which you can guarantee the continued safety of the airplane. This article is intended to show you how the flight envelope is worked out, what it means to a pilot, and finally, how it will be affected if you try to increase the weight of the airplane.

The first things that an airplane designer needs to know when calculating the flight envelope are the g-limits and something called the torsional divergence speed.

The g-limits vary according to the type of airplane being designed. If they were designing a jet fighter or an aerobatic display aeroplane he or she might pick around +9g and -4g. For a glider the maximum g is usually at least +5.3g. For an ultralight, typical g limits are +4g and -2g, which (since nobody in their right mind would want to pull more than 4g in an ultralight) are almost universal. Before flight, the airplane wings (and other bits) are tested to these g-limits plus a 50% safety factor by loading them up on the ground. That means that for a 4g ultralight, the structure should have been tested to at least 6g without breaking (or at least only bending a bit) at the maximum take-off weight.

The torsional divergence speed (V_{div}) is something calculated at the design stage and is the speed at which the wings will fall off when you fly much too fast. The designer then wisely applies a safety factor to this to provide him with the design diving speed (V_d or sometimes V_{df}) which is the fastest he’s prepared to let anybody fly at.

Armed with these pieces of information, the designer can then give the test pilot a diagram like this, which is his **initial flight envelope**.

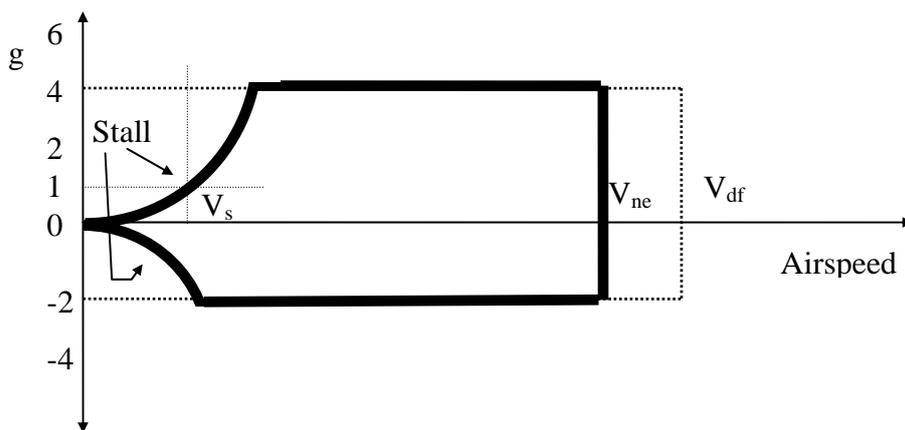


Now this is a useful starting point for the test pilot and it gives him enough information to, very carefully, explore the airplane’s handling up to a (hopefully) safe

maximum speed. Occasionally the airplane's handling turns out to become too poor at some high speed below V_{df} , in which case the test pilot and designer will between them agree a lower value of V_{df} . However, the envelope is still far from complete because it's obviously absurd for the airplane to pull 4g (or even stay flying) at, say, 10 mph. So another thing the test pilot will be doing is testing the stall speed. Once the stall speed at the maximum weight is known, this can be added into the flight envelope. The way the designer does this (because they're clever people and can do maths) is to say:-

1. The stalling speed at 1g at the maximum take-off weight is V_s .
2. But lift, $L = \frac{1}{2} \cdot \rho \cdot V^2 \cdot S \cdot C_L$. (ρ = air density)
3. Since at stall and 1g, lift = weight and C_L , the lift coefficient = C_{Lmax} , the maximum lift coefficient; we then get $W = \frac{1}{2} \rho V_s^2 S C_{Lmax}$.
4. If we re-arrange all of this, I can say that the stalling speed at any g loading is proportional to the square root of the speed with V_s being at 1g.

The designer then re-draws the diagram with a stalling speed curve on it. At the same time, because only test pilots are supposed to fly right up to V_{df} , a safety factor gets put into the top speed and a slightly lower speed, V_{ne} , gets put onto the diagram. So, we get (nearly) the final flight envelope.

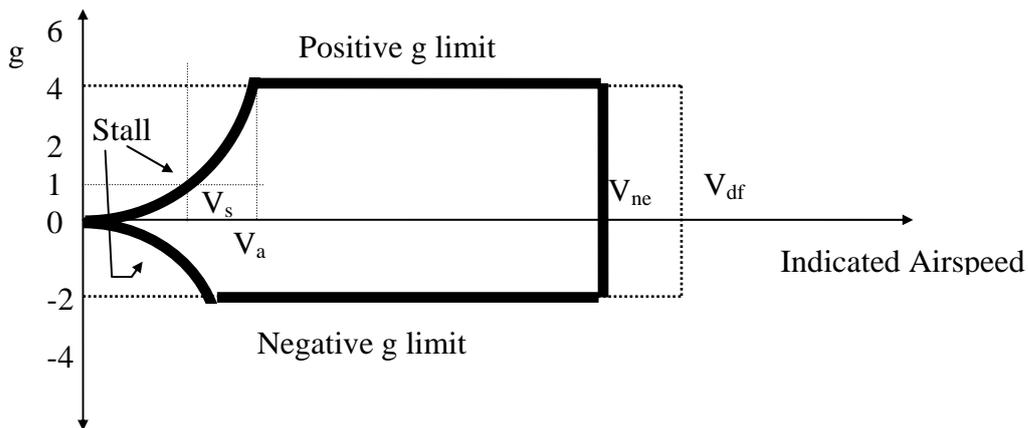


This is nearly the full flight envelope, and the airplane can be flown anywhere within the dark box on the g-Airspeed (often called V-N) diagram quite safely. However because the designer's a clever chap and can not only do maths, but understands aerodynamics as well, there are a couple of extra tricks to get through before finishing.

Firstly the designer looks at the lift equation and spots the term $\frac{1}{2} \cdot \rho \cdot V^2$, sometimes called dynamic pressure. Conveniently this is the quantity that is really measured by an air speed indicator (ASI). So, the diagram can be changed to read "Indicated Airspeed" and only one diagram is needed and not one for every height (since the air density, ρ , changes with altitude).

Finally the designer thinks about the top right hand corner of the graph, where if the pilot tried hard enough they could pull more than 4g and possibly bend the wings - an

action which both pilots and engineers are agreed is a bad thing. On the left hand side of the graph, this wouldn't be possible because the wings would stall before enough g could be pulled to break them. So the designer calls the airspeed at which the airplane would stall at 4g (the top left corner of the graph) the manoeuvring speed, or V_a . He or she then inserts a note in the airplane handbook telling pilots that they should not use full control deflection above V_a since that could damage the airplane. And finally, we have the final flight envelope, which gives the stall speed(s), never exceed speed, g-limits and V_a - the manoeuvring speed. And it looks like this:-



Having done all of that, and to keep things simple for the pilot who's far too busy to remember different limiting speeds for everything the designer will also ensure that any other primary controls (such as ailerons or a rudder on a 3-axis ultralight) are stressed to take full deflection up to the same manoeuvring speed - which is why most airplane manuals refer to V_a as the "Maximum Speed for full deflection of flight controls". Flaps, if fitted, are classed as a secondary control and may have a separate maximum speed, usually called V_F .

What about the weight?

The normal flight envelope given in an airplane manual is based upon the maximum take-off weight - lets say in this case it's 250 kg. As the weight reduces it becomes more and more safe because loads upon the wing at any given g-level are reduced. In ultralights, although it's possible to define several envelopes for different weights - it's normal to use only the one, safest envelope. BUT - if you increase the weight then this envelope becomes less safe. A 250 kg airplane flying at 290 kg would have its 4g limit reduced to less than 3½ g. In the same airplane V_a would reduce by about 15% and the stall speed would increase by 8%. All of this would usually reduce the safety factors below a level should be properly considered safe.

This does mean that unless you wish to re-do all of the load tests yourself on your 250 kg ultralight to show that it is good for 290 kg at 6g (and risk breaking it in the process) you should really stick with the current maximum weight until you buy a new airplane which is rated for a higher weight.

