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HOW EASY IS IT TO CAUSE STRESS?

We understand stall speeds, but what of cruise speeds and the effects of turbulence and over-exuberant control inputs?

Two young student pilots were propping up the clubhouse bar, pondering over a question in a sample PPL airframes paper they had both been doing to while away the time, their flying slots having been cancelled due to the weather turning sour a couple of hours previously. The question was over how strong an aircraft had to be to cope with 'g' loads in flight. Casting his mind back to school physics lessons and a dimly remembered Newton's laws, one hazarded: 'If the total weight of the Cessna including fuel, crew and baggage is 1500 pounds, then if it has to cope with a 4g acceleration then the wings have to carry four times 1500 pounds i.e. 6000 pounds, right? So I guess we tick box A?'

The other, who had spent the morning with his nose buried in a dog-eared copy of the club's Airframes and Engines text book, rejoined - 'Yes, but you've forgotten the safety factor. Aeroplanes have to be able to carry at least 50% more load than the pilot might want to use, to give an extra margin of safety. That means your Cessna's wings have to be good for an extra 3000 pounds, giving a total of 9000 Lbs. So tick multiple choice box B'.

The two pilots marvelled over the fact that by their reckoning their humble club Cessna, which weighed less than an old-style Issigonis Mini, had to be able to carry the weight of two transit vans. 'It just shows', said one, 'how enormously strong these aeroplanes are and how hard pushed you'd have to be break one in flight'.

'Not so fast, young man' rejoined the grizzled CFI, who, sunk deeply into a barely-recognisable armchair in another corner of the clubroom, had been gloomily working out the effect on the club's turnover of yet another weekend of cancelled lessons. It really had been a terrible summer... 'First of all, that extra 50% safety factor wasn't put there for the likes of you two to play with, once you start going into that territory then you're going to be damaging my aeroplane for sure, even if the wings do stay attached – which is doubtful. You'll be coming back with the whole airframe overstressed and only fit for scrap. Even if there are no obvious external signs like puckered skins or bent wing spars, carrying on flying an aeroplane that has been overstressed means it may collapse later when some other poor mutt is flying it.'

'And another thing, most of our 'planes have been around longer than you two lads, and have been slogging the circuit for decades – much longer than the designer probably had in mind when he drew up the thing - been repaired a few times too, if you care to have a look in their logbooks over there..... riveted joints are prone to corrosion you know..... despite the best efforts of our maintenance chaps, these airframes can't be as strong as the day they left the factory. That's part of the reason airframes are designed with the extra 50 % safety factor – to allow for degradation in service. And of course, designers like to have the factor there to give a little leeway in case they have made a mistake or two in their calculations – slide rule slipped, or they multiplied by 'pie' instead of 'alpha', too busy thinking about lunch.....!'

'Six thousand pounds sounds like a lot of load to put on a little aeroplane's wings, and it is – three tons give or take a bit.... Not bad considering each of a Cessna's wings only weighs a hundred pound or so, which just shows what efficient structures they are.....have to be, if you built 'em like the Forth Bridge you'd never get off the ground. Aeronautical engineers have to pare off every bit of unnecessary weight. If weight wasn't a consideration, the safety factors

would be much higher, like in most other industries. Ironic isn't it, that in an aircraft, where collapse of the structure almost inevitably has fatal consequences, we have lower safety factors than in ground-based vehicles where failure would most likely just mean having to take the bus home?'

'How easy is it to overstress them? Well, you know there's an interesting little fact buried in the design rules that apply to almost all light aeroplanes, microlights and gliders, which is that the backward force the pilot would have to apply on the control stick grip in flight, to make the aeroplane reach the 'g' load where it starts to suffer structural damage, must not be less than fifteen pounds. This is intended to ensure that pilots can't overstress aeroplanes inadvertently. But think about it, fifteen pounds is a force so low that you can just about hold it with your little finger – you can manage more if you are in training from carrying the dratted plastic bags of shopping away from the supermarket. So only the force of one little finger may stand between you and a bent aeroplane....'

The students were deflated. Surely, even taking into account all this, 4g was a lot, much more than you ever need in a simple Cessna. Surely there was no reason to worry about it providing you just flew normally – after all, these aren't aerobatic 'planes.

THE STALL TO CRUISE SPEED RATIO AND ITS POTENTIAL EFFECT ON STRUCTURAL INTEGRITY

Behind the storyline above lurk some really important issues, and dangers that are becoming increasingly important with the newer, faster breed of microlight and VLA aircraft and the more challenging types of flying now regularly being undertaken. Faster speeds bring more potential for high 'g' problems. To calculate the 'g' that can be pulled inadvertently in an aeroplane, divide the speed the aircraft is flying at by the aircraft's stall speed in that configuration and then square the result – so flying at twice the stall speed means you might pull four 'g', four times the stall speed equates to a mind-numbing 16g. Whereas the older types of traditional homebuilt such as Luton Minors and Currie Wots had a relatively slow cruise speed of barely twice the stall speed, and were therefore largely proof against being overstressed in flight, today's machines such as the RV range, Europa and so on have the capability of cruising at more than three times the stall speed and could therefore relatively easily be overstressed in flight – flying at three times the stall speed means that up to 9g might be reached with too much 'back stick'. If the airframe is only designed to cope with 4g then it will most likely not survive.

VA - MANOEUVRING SPEED

To stay out of trouble with the airframe, you have to fly with three safety speeds in mind. The manoeuvring speed V_a (pronounced 'vee-aye') is the maximum airspeed you can fly without risking structural damage if you carry out abrupt manoeuvres. Confusingly, that's not to say you mustn't manoeuvre at speeds above V_a , it simply means that if you do then you must be careful not to pull too much 'g', to avoid overstressing the aeroplane. If you fly at less than V_a then no matter how much you pull (or, for that matter, push) on the stick, the aeroplane will stall before it reaches the maximum manoeuvring 'g' which it has been designed to carry. You'll almost invariably find V_a quoted in the aeroplane's flight manual in the 'limitations' section, on the Permit to Fly or in the manufacturer's data.

Sometimes this speed is referred to as 'maximum speed for full control deflection'.....this is a bit misleading because it rather implies that if you fly at a speed a bit above V_a then you will be OK providing you use a bit less than full deflection, which is not necessarily the case. Depending on the stability and control power of the aeroplane, and in particular its centre of gravity position and trim setting, it may be possible to reach high g levels without the stick being far from neutral. In an unstable aeroplane, you might even find that the stick has to go *forward* of neutral just to stop a steep turn 'tightening up' on you. Not that PPLs normally get a chance to fly such unstable aeroplanes – but it can happen, especially on older types, or if they are mis-loaded with an extreme aft cg.

When flying at speeds above V_a , the risk of overstress and structural failure is there, whatever reason you manoeuvre. Not all manoeuvres are planned, and it may be the spontaneous response to some external cause which leads you into danger – for example the Zenair pilot who was flying a low pass over a farm strip at high speed when he spotted wires close ahead, pulled up sharply to clear the wires – and caused a structural failure of his wing attachments, with consequences fatal to himself and his passenger. The Zenair, like many VLA and microlight aircraft, has light stick forces and would have needed only a 25 Lbs pull on the stick to cause such a catastrophic structural failure. High speed, light stick force and exuberant flying make a dangerous blend.

VNO – MAXIMUM ROUGH AIR SPEED

The second safety speed to be aware of is the normal operating limit, V_{no} ('vee-en-owe'), which is the maximum speed the aircraft is designed to be able to cope with in gusty or turbulent conditions without being overstressed. It is based on an intensity of so-called sharp-edged gust which is slightly arbitrarily assumed to be 50 feet per second, in other words the whole aeroplane is assumed to have to transition straight from one lump of air which is static into another which is going up at 50 feet per second – like a high-power thermal. Putting it in simple terms, the faster you are going when you slip from one air mass into the next, the bigger the jerk required to accelerate the aeroplane from level flight to a 50 foot per second climb. To hit the vertical gust at high speed gives you a hell of a jolt, as you can imagine. Go too fast and the jolt will overstress the aeroplane.

Of course in actual bumpy air you are usually encountering pretty much random gusts in all directions, but the 50 foot per second model has been found to give equivalent loads, based on the highly detailed instrumented results of some brave RAE and NACA pilots who were sent up to explore turbulence of increasingly severe magnitude, just after the last war. Some of these pilots didn't come back, having found (like many glider pilots before them) that the violence inside a thunderstorm was more than their airframes could cope with.

V_{no} is generally a few knots faster than V_a . Again, you will find V_{no} stated in most aeroplane flight manuals, and it is the bottom end of the yellow arc (the cautionary range) on the ASI. If in doubt, use twice the stall speed. For the pilot, the message is that unless the air conditions are smooth, with negligible turbulence, you should not fly at a speed greater than V_{no} otherwise you will risk overstressing the aeroplane if you hit a strong gust. Slow down to give yourself a more comfortable ride, and save your aeroplane's structure. Hitting a severe gust at high speed will cause 'g' levels as high as pulling the stick hard back – but you may not be aware of the danger because of the effect is an instantaneous jolt rather than a sustained acceleration that can be felt through the seat of the pants, arms like lead etc.

We are not talking academics here; there have been several accidents in the last decade with structural overstress through hitting turbulence. In one case, the pilot who was flying near vertical cliffs on a windy day appears to have made the fatal mistake of increasing speed on encountering the turbulence, to get away from the area of rough air – and lost his wings. The pilot of another aircraft, flying in company with the first, chose to slow down - and survived, but with some airframe damage.

VNE – NEVER EXCEED SPEED

The final safety speed is the most well known, the never-exceed speed V_{ne} ('vee-en-ee'). This speed is indicated by the short red radial line and the top end of the yellow arc on the ASI. This is the airspeed that the aircraft is designed to cope with (usually, but not always, necessitating a dive) but only in calm, turbulence-free conditions. The airframe is normally designed to be able to cope with a much lesser intensity of gust at V_{ne} , usually equivalent to only a 25 feet/second sharp-edged gust. This is to cater for the fact that even on an apparently turbulence-free and calm day there is always a risk of suddenly encountering an isolated piece of mild turbulence such as a stray thermal, or the remains of the wake turbulence from some other aircraft which has since moved on. Encountering a 50 foot per second gust (i.e. a severe one) at V_{ne} would most likely cause a collapse of the structure.

The other limiting factor is that Vne is usually the highest speed that the aircraft is guaranteed by the designer to be free of flutter problems – he will most likely have proven the prototype to a very slightly higher speed than Vne (normally just 5%) to show that there is some safety margin, and to provide for minor differences between one aeroplane and the next, the effect of wear and changes in the friction levels in the control system with age, and variations in the airspeed indicator errors. As high-speed flutter can tear an airframe apart in fractions of a second, this is not a phenomenon to be risked by ever going above Vne, outside of a proper factory test program – or one authorised specifically by CAA, BMAA or LAA - not for nothing do test pilots get paid to do this sort of thing - they have to wear a parachute, and usually have jettisonable doors fitted to improve their chances of escape.

Apart from the fact that modern light aircraft and microlights often cruise at three or even four times their stall speeds and are therefore vulnerable to overstressing, the streamlining of the airframe and close attention to cockpit seals which are required to achieve this high performance causes a further risk, which is that the pilot has fewer visible and audible cues to warn him that he is flying fast. Flying older aircraft, you find that increasing the airspeed much above normal cruise means a steep dive and a roaring wind noise from the air whistling through all the leaks in the cockpit canopy – or around the windscreen of the open cockpit. You would have to be deaf as well as blind to miss the fact that an aeroplane like this were being flown faster than normal – which is why in these types of machines it is not a big deal if the ASI fails in flight. It is quite easy to fly, manoeuvre and land these aeroplanes just using the visual and audible cues as a measure of correct airspeed – and even if the approach is flown a mite fast, to be on the safe side, the high drag means they won't float very far so a safe landing can be made.

With a streamlined well-sealed aeroplane, by contrast, their higher lift/drag ratio means that in the cruise the nose only has to drop a few degrees to let the speed slip quickly past Vno and even past Vne. The lack of wind noise and drafts in the cockpit makes it impossible to tell your speed that way. Throw in a bit of bad visibility robbing the pilot of a proper horizon, extra workload with navigation due to having to divert, reaching behind for that flight guide or what have you, and the possibilities for inadvertent overspeed become very real in these slippery modern aircraft. Approach and landing with a failed ASI (all it takes is a little water in the pitot pipework) is also much more difficult with these machines – especially if they haven't got very effective flaps. The more powerful the flaps, the more they reduce the lift/drag ratio which in turn means that the change in glide angle becomes much greater (more perceptible) for a given change in speed.

CONCLUSION

Fly too slowly and you may stall – fly too fast and there are equal or greater perils. To fly safely, understand your aircraft's flight envelope and speed limitations and, with modern slippery aeroplanes in particular, the importance of taking into account turbulence when deciding your cruise speed. If the ride feels uncomfortable, you are probably going too fast for the conditions.