INTERNATIONAL AEROBATIC CLUB

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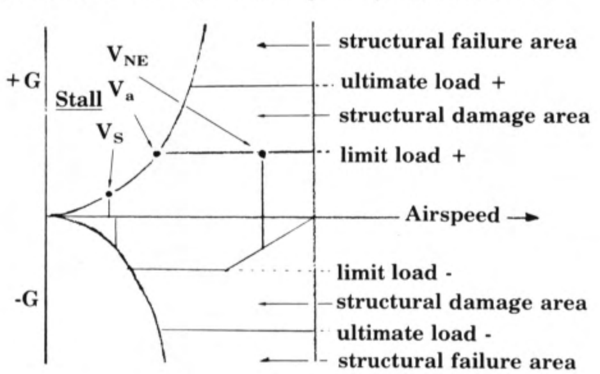
MEMBER

SNAP ROLLS AND INDUCED LOADS

As all IACers know, snap rolls (flick rolls) and the loads induced by snap roll maneuvers are great topics for hangar conversations. Some information recently supplied by IAC member Montaine Mallet should help us better understand snap loading and provide more material for those hangar debates.

To get us all started on the same wave length let's review some background material on aircraft strength requirements. The criteria for aircraft strength is pretty well spelled out in Part 23 of the (USA) Federal Aviation Regulations. Aircraft manufacturers (those producing type certificated aircraft) must conform to these regulations. Aerobatic category aircraft according to Part 23 must withstand flight load limits of +6 Gs and -3 Gs. In addition to the +6 and -3 limits, Part 23 calls out the criteria for a complete aerobatic flight maneuver envelope. (Sometimes these maneuver envelopes are called V-G diagrams, V-a diagrams, or V-N diagrams — all the same thing.) A typical aerobatic flight envelope may look like this:



V_S = stall speed (unaccelerated, gross weight)
V_a = maneuvering speed (gross weight) (end of green arc)
V_{NE} = never exceed speed (red line)
The above is kind of a simplified envelope. More details can be found in Part 23.

Before continuing, a few items should be mentioned. Three very important things to remember when looking at an aerobatic flight maneuver envelope are (1) all the airspeeds and loads noted on the envelope are for the airplane at gross weight, (2) the envelope is just for loads in the X-plane, i.e., elevator controlled pitch loads (rolling and yawing loads are NOT shown on the envelope), and (3) the limit loads shown are for symmetrical loading. IACers should also note that the Part 23 criteria is the minimum requirement.

Some acro aircraft may be stronger than what Part 23 calls for but have only been tested to the Part 23 limits. It is also possible to test and certify beyond Part 23 requirements which is what Bellanca did with the Decathlon which has a negative limit load of -5 G which is two greater than the required Part 23 -3 G limit.

And IAC members operating Citabrias and some of the old aircraft should remember that while these aircraft are type certificated aerobatic category aircraft, they were certified under the old Part 4 criteria which is not as stringent as Part 23 criteria. And also note that gust loads are not shown on our simplified maneuver envelope. If you are pulling +6 Gs and hit a 2 G gust, you just subjected your aircraft to +8 Gs.

Enough digression. When discussing snap rolls we are interested in the maneuver envelope between V_S (unaccelerated stall speed) and V_a (maneuvering speed). You can find several definitions for maneuvering speed. One of the definitions for V_a that kind of relates to aerobatics is given in the FAA Flight Instructor's Handbook. It is ". . . the (maximum) speed at which full sudden deflection of the flight controls will not cause structural damage."

Looking at the flight envelope, we see that V_a is at the intersection of the "stall speed line" and the "limit load line." Therefore, the above definition makes sense. For example, if we abruptly apply full back stick at any speed less than V_a we cannot generate enough lift force to overstress the aircraft. Simply, the airplane stalls before it can be overstressed. Another way to look at it is, for a Part 23 acro aircraft you can't pull +6 Gs at speeds less than V_a.

If you know the stall speed of your aircraft you can easily compute the airspeed to maximum G relationship.

$$\left(\frac{\text{Airspeed}}{\text{Stall speed}}\right)^2 = \text{load factor, G}$$

(This is the maximum G that you could pull at the specified airspeed.)
For example:
Given: stall speed of S-1S Pitts at 1150 lbs = 62 MPH IAS
What is max. G factor at 107 MPH IAS?

$$G = \left(\frac{107}{62}\right)^2 = (1.73)^2$$
$$G = 3$$

Obviously, you can use the above relationship to generate the section of the flight maneuver envelope between stall speed V_S and maneuvering speed V_a.

O.K., therefore, you should be able to safely snap roll any aerobatic aircraft at V_a or less — right? WRONG! Recall the limit loads defined by the maneuver envelope applied only to X-plane (elevator-pitch) loads and only to symmetrical loading. In addition to elevator input, snap rolls require rudder deflection (and as some pilots/aircraft prefer, aileron deflection). Therefore, snap rolls load the aircraft in more than one axis (or plane) and do not produce symmetrical loading.

The rule of thumb for rolling and pulling or rolling and pushing maneuvers is to reduce the load factor to ¾ or ⅔ of the maximum limit load. The Bellanca Decathlon is stressed for +6 G and -5 G and the flight manual states "full and or abrupt movement of ailerons may be used at any speed up to V_a provided that the load factor does not exceed +4 Gs or -3.2 Gs." Note "+4" and "-3.2" are approximately ⅔ of the limit load factor.

O.K., because snap rolls are pulling-rolling/pushing-rolling non-symmetrical loaded maneuvers you know your maximum G limit in a snap should be somewhat less than the maximum limit load the aircraft is designed (certified) for. You also know that the maximum limit load is based on the aircraft's gross weight; so if you fly your aircraft at less than gross weight, you should be able to safely pull higher G loads — right? WRONG!

Consider snap rolls first and the flight maneuver envelope between V_S (stall speed) and V_a (maneuvering speed). Say your aircraft has a gross weight of 1650 and a stall speed of 51 MPH at gross. And, for example, the flight manual gives a recommended snap roll entry speed of 85 MPH. From the above you calculate that you should pull about 2.8 Gs on a positive snap.

$$\left(\frac{85}{51}\right)^2 = 2.8 \text{ G}$$

But instead of flying at 1650 lbs, you are flying at 1375 lbs. If you still use an 85 MPH snap entry speed, what +G do you pull? Well, you know at a lesser weight the stall speed will be less. In fact, the stall speed will decrease as a ratio of the square root of the new weight to the gross weight. So you calculate the new stall speed as:

$$\sqrt{\frac{1375}{1650}} = .91$$

$$.91 \times 51 \approx 45 \text{ MPH}$$

and the G load in a snap at 85 MPH entry speed as:

$$\left(\frac{85}{47}\right)^2 = 3.3 \text{ G}$$

If you reduce the flying weight and keep the same snap entry speed, you will increase the G load imposed on the airplane. Check out the maneuver envelope. If you fly the aircraft at a weight less than gross, the stall speed will be reduced, the maneuvering speed will be reduced, and the flight maneuver envelope between V_S and V_a will shift to the left. Therefore, if you fly at a weight less than gross, you should reduce the snap roll entry speed. In our example, a snap roll at 1375 lbs entered at 79 MPH would produce the same G load as a snap at 1650 lbs entered at 85 MPH.

O.K., you believe that a lesser flying weight calls for a lower snap roll entry speed, but because maximum limit load (G) is based on gross weight, you should be able to fly to a higher maximum G limit, right? WRONG! For example, if your aircraft is a type certificated Part 23 aerobatic category aircraft and is approved to +6 G at 1150 lbs gross weight, you figure that the aircraft is stressed for 6 × 1150 lbs, or 6900 lbs. Therefore, if you fly at 1000 lbs instead of 1150, you should be able to pull 6.9 G

$$\left[\frac{6900}{1000} = 6.9\right].$$

That may be true as far as the wing loading goes, but this line of reasoning does not take fixed weights, such as the engine, into account. The engine mount may be stressed for 6 Gs, i.e., 6 times the engine weight, and reducing the overall flying weight, for example, by flying with less than full fuel does not reduce the engine weight. Therefore, increasing the load from 6 to 6.9 may overstress the engine mount. Maximum G limit means maximum G limit, and flying at a lighter weight does not necessarily bump that limit.

Hopefully now, everyone is pretty much tuned in on flight loads induced by snap roll maneuvers and how to relate G limits and entry speeds and flying weight to the limits defined by the aircraft's maneuvering envelope. We've got a handle on snap rolls, right? WRONG again! Unfortunately, we have been lead down the old primrose path — but it was kind of necessary to get a little basic understanding squared away before expanding our horizons.

Recall in the beginning of this article it was stated that Montaine Mallet had forwarded some info that would help us better understand snap roll loading? The following is part of the letter the IAC Tech Safety Committee received from Montaine. Montaine's letter "changes the rules" a little bit.

"The French manufacturer, Avions Mudry, did some research on the subject of snap rolls. It all started when they realized that clean aircraft, although not only calculated, but tested and certified for a certain load (let's say the same load as a certified biplane), would show cracks in their spars (and the biplane would not) — although they would be used similarly. For example, Leo Loudenslager has a history of finding his spar cracked as well as some Stephens Akro, Laser and CAPs. Of course, a lot (and most of those, actually) are due to overstressing and flying outside the envelope (higher speed and higher G than certified for). But still, proportionally there are many more cracked spars found in monoplanes than in biplanes — although structurally speaking they are supposed to be the same strength. It was also obvious that aircraft performing snap rolls a lot were the prime target.

"To make a long story short, they made some tests in wind tunnels where they could measure the lift coefficients for different angles of attack induced with different forces.

"You know that each airfoil has a definite curve relation between the angle of attack and the coefficient of lift with a maximum coefficient of lift which occurs at stall angle of attack. This maximum coefficient of lift is used to determine the maneuvering speed, the maximum load, and, therefore, define the structure of the aircraft for a particular purpose. This is why you hear that as long as you do not exceed maneuvering speed for maximum deflection of controls, you will not overstress your aircraft.

"Well, in those tests, they found that if you deflect the elevator very rapidly or abruptly, changing the angle of attack very rapidly (as in a snap roll), for a split second it will change the coefficient of lift of your airfoil. It is like it was actually changing the airfoil and making it more curved. The maximum coefficient of lift might increase up to two or more times what it was and, therefore, all your calculations are wrong.

"Of course, all those tests lacked precision: how fast, how brutal you pull? What are the effects of the other controls? Do they also have an effect on the coefficient (like when you use the ailerons, etc.)? But, at least the fact that the coefficient of lift changes was well established.

"Now, why does it affect mono-wing-clean aircraft more? It is easy to figure out: when you snap a biplane the drag of the aircraft itself and the huge amount of drag induced as you increase the angle of attack makes the change probably a little slower and, therefore, the change in the coefficient of lift smaller at slower speed. The cleaner the aircraft is the worse the effect will be. It also depends on the kind of airfoil, of course. The symmetrical airfoil, for instance, has much more drag to start with than a semi-symmetrical airfoil such as what is used in the Laser and the CAPs.

"The subject is endless and if there was money and time there would be a lot of interesting things to be discovered during snap rolls. At this time there is enough knowledge to make some recommendations: snap rolls, especially in clean aircraft, do not have to be brutal, just quick, and the airspeed should be way below maneuvering speed. They have to be established based on experience rather than calculations, but the last few years of monitoring the problem have proven the recommendations to be appropriate. I am enclosing, for your reference and information, the recommendations that Avions Mudry had included in the owner's manual of the CAP 10B.

"For an aircraft without a long history (where you end up knowing the weak points) or appropriate tests (which usually are too expensive for homebuilt or modified aircraft), I would follow the same recommendations (adapted to the envelope of the particular aircraft, of course) — and check my spar after the first year of use. It is usually fairly easy to know which part of the spar is going to fail first according to the building concept."

It took us a long and extended introduction to get to the heart of this article, Montaine's letter, so that everyone, even the guy who joined IAC yesterday, would be up to speed. But we feel that the importance of Montaine's/Avions Mudry's information was such that it warranted some background preamble.

Perhaps just as important as the specific information relating to coefficient of lift changes with abrupt control inputs was the point that field experience is the bottom line. The best engineers, the best computer simulations, the best craftsmen, etc., can get us very close, but it is the actual in-field usage that gives the REAL answers. Our knowledge of snap roll induced loads is greatly expanded because of things like Avions Mudry's testing, but the real snap roll entry speed numbers come from field experience.

IAC provides the opportunity for us all to learn by pooling our knowledge and experiences — for our mutual benefit. Thanks goes to Montaine for providing the Avions Mudry info and for sharing what she has observed. IACers are encouraged to follow her example.

P.S. Excerpts from the CAP 10B flight manual mentioned above follow for they provide excellent examples of items noted in this Tech Safety article.

CAP 10B p. 7.1

VII. 1 **FLIGHT ENVELOPE**

The subject of this chapter is to specify the limits of the aircraft envelope which should be STRICTLY respected when flying the aircraft.

For the aircraft as defined, the structural resistance has been demonstrated for all combination of speed and load factor situated inside that envelope. All overstepping can result in structural damage to the aircraft.

VII. 2 **ENVELOPE LIMITATIONS**

2.1 **DEFINITIONS:**

Speed Vs — Stall speed with clean configuration and positive flight (+g)

Vs' — Same as above but is negative flight (-g)

Va — Maneuvering speed: speed above which full deflection of any one of the flight controls is forbidden.
Va = 235 Km/h = 146 mph

Vne — Never exceed speed
Vne = 340 Km/h = 211 mph

2.2 **SYMMETRICAL MANEUVERS:**

2.2.1. **Positive Load Factor**

The CAP 10B is limited to operations up to a load of 6g until 211 mph.

2.2.2. **Negative Load Factor:**

The CAP 10B is limited to operations up to a load of -4.5g until 186 mph.
This limit decreases after that from -4.5g at 186 mph to -2.6g at 211 mph.

2.2.3. **Remark:**

Because of the maximum value of the steady lift coefficient of the wing, the +6g load factor cannot be reached between speeds of 60 mph and 146 mph. If you look at the envelope diagram, the plane stalls beyond the dotted line. For negative flight, same thing, -4.5g cannot be reached between 86 mph and 175 mph. (Remember this is for symmetrical maneuvers and steady flow configuration, no abrupt maneuvers).

2.3 **NON-SYMMETRICAL MANEUVERS:**

Full deflection of any one of the flight controls is authorized up to 146 mph, no matter if you are in negative or positive and with reservation that you are staying in the flight envelope.

Remark on the ailerons:

Beyond 146 mph and until 186 mph, the deflection of the aileron must not allow a rate of roll bigger than the one obtained at 146 mph with full deflection of the aileron. At 211 mph, the deflection must not allow a rate of roll bigger than ⅓ of the one obtained at 146 mph with full deflection.

2.4 **SNAPPED MANEUVERS:**

Recent wind-tunnel tests have shown that quick variations of the angle of attack can increase substantially the maximum coefficient of lift of airfoils (unsteady flow). For this reason, the full and quick deflection of the elevator at speeds below or equal to the maneuvering speed (146 mph) can cause the overstepping of the limit load factors and could cause breaking.

Because of that, the maximum authorized speeds for snapped maneuvers are:

positive: 110 mph
negative: 125 mph.

VII. 3 **REMARKS:**

3.1 **TURBULENT AIR - GUSTS**

For example, at 186 mph, a vertical gust of 5 m/s (985 ft/mn) will result in an additional 1.5 g and a 10 m/s (1970 ft/mn) gust will result in an additional 3 g.

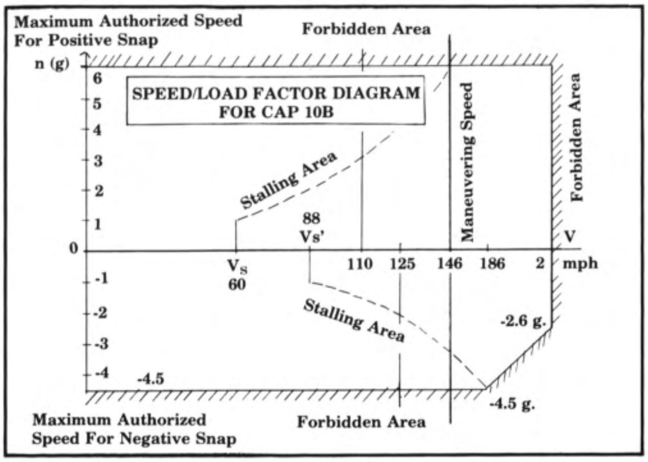
The superimposition of such a gust to a regular maneuver normally performed at 3 or 4 g can bring the aircraft outside the envelope.

Therefore, aerobatics in turbulent air must be performed with lower speeds and g loads.

3.2 **OPERATING WEIGHT**

The CAP 10B is certified for a maximum weight of 1675 lbs in Aerobatic Category. Contrary to a lot of rumors, when a pilot flies solo, with a smaller total weight, the g load limitations should still be respected.

Indeed, only the wing spar supports less load if the weight is less, but, the rest of the structure (fuselage, engine mount, wing caissons of torsions etc. . . .) support loads proportional to the acceleration or to the speed square, independently of the aircraft weight.



MALLET ADDENDUM:

The above Tech Safety article based on Montaine Mallet's/Avions Mudry's input centers mainly on snap roll induced loads. However, when dealing with this subject it is hard to separate snap roll loads from aircraft load limits. The foregoing article touched somewhat on the aircraft loads in general. Part of Montaine's letter to the IAC Tech Safety Committee also commented on aircraft stresses and is well worth reading.

"While we are on the subject of G, it might be a good time to remind pilots what an envelope is defined for. I have heard too often, and I am sure you have too: 'Well, my aircraft is certified for +6, -6, but I know I can take more. I already pushed it to 7.5 a few times and it held.' Fortunately, it did; the certification numbers guarantee that it will not fail the first time overstressed for at least 1.5 times those numbers which means, in this example, +9, -9. So, of course, it will not fail even at 8 G — but for how long and how many times?

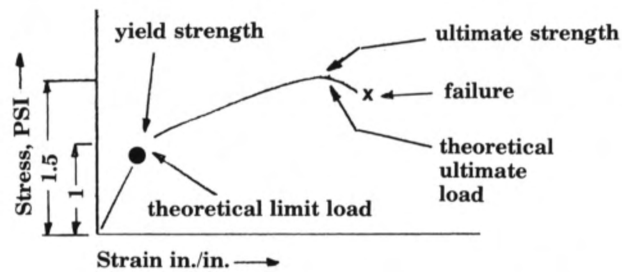
"As soon as you pass the 6 G limits (in this example) you do not really know what happens. Aircraft are tested to the breaking point to make sure it will not break the first time below 9 (in our example). But they are not receiving many 7 or 8 G repeatedly before breaking thëm. It would be impossible, financially and even practically, to establish a pattern of how many times you can exceed before it fails.

"For a metal aircraft, as soon as you pass the 6 G (in our example) you take high risk of fatigue and permanent damage. Actually, in a metal spar you even will have fatigue even if you never exceed the G which is why it is recommended to dye penetrate the weak point once in awhile (usually based on experience). For a wood spar, after the 6 G you might have some compressed fibers which are hard to see and it is also very hard to know when they will occur because the quality of the wood can be so different from one aircraft to the other. A minimum resistance has to be met, but the wood could be better and therefore resists better. This is why we say, for a wood spar, if you stay in the envelope you will always be safe (at least in that aspect).

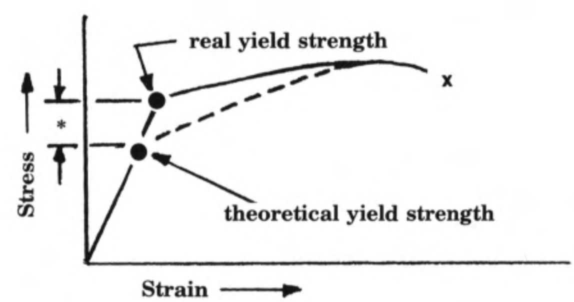
"If you exceed G, then use common sense and the next time available check your spar. The aircraft does not have to be grounded immediately (unless you took 9 G, in our example) because it will take awhile for the compressed fibers to start a crack which will find its way through the spar. But meantime, it will weaken the structure. So, someone who often exceeds speeds and G should make a point to check spars and other critical parts every winter.

"What we emphasize in our school a lot is: respect the machine and it will respect you. Never use it outside of its envelope and if you do, please check your aircraft. A machine that has been properly certified or has been on the market for long enough to be proven safe will never fail you without giving you enough warning if you pay attention."

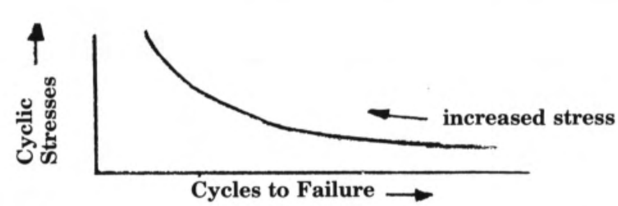
In the foregoing article it was mentioned that some acro aircraft have been tested to the minimum strength requirements defined in FAR Part 23 and are certified at these limits but that does not preclude the possibility of these aircraft being capable of sustaining higher loads. To repeat, that is a POSSIBILITY. But to pick up on what Montaine points out, when you explore beyond the published limits you may be on shakey ground. If an aerobatic aircraft is FAA certified, for example, to a +6 G limit load, it must have a safety factor of 1.5 and, therefore, an ultimate limit of 9 G ($6 \times 1.5 = 9$). Considering stress-strain, you get a theoretical curve which looks like this:



In real life things are slightly different. For some aluminum parts, for example, the stress-strain curve could look like this:



The difference between the theoretical yield point (e.g., at +6 G) and the real yield point (+6 G plus) is an area above the limit load where one could fly and should theoretically sustain damage but where one might find no apparent damage. Note in both the theoretical case and the real case, the ultimate failure point is at the same stress level. To further appreciate what could happen if you do exceed the published limit loads, one should look at a fatigue life cycle curve. This curve would look something like this:



Simply, the higher the stress level, the fewer number of cycles until failure. One of the most dramatic examples of this is mentioned in Neil Williams' book, AEROBATICS, where it is stated that a Zlin 526A is certified for +6 G and -3 G with a service life of 2200 hours. If the same aircraft is flown to competition standards of +8 G and -6 G, the airframe life is reduced to 100 hours.

In life and aerobatics there are no free lunches.