THE NATURE OF FLIGHT LIMITATIONS

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(Recent incidents and subsequent reviews have shown up a number of popular misconceptions in interpreting sailplane flight limitations. The following discussion of the design philosophy may help pilots to better appreciate the limitations of their machines.)

Who needs design standards anyway?

In contrast to vehicles and boats, aircraft have only emerged as a means of transport in the last 90 years. From early days the risk associated with their operation was so obvious that design was regulated with a view to protecting the pilot, passengers and the public at large. The prime aim of requirements is to define a necessary strength minimum giving due regard for the imprecision and tolerances of the design and construction processes. These limitations should also enable the designer to provide an attractive and performing product with maximum commercial efficiency and not overburdened with unnecessary capabilities and complication. Consider that when you discuss the merit of a particular new acquisition with your syndicate partners, the conversation is generally confined to the finer points of performance and handling. The airworthiness of the basic design is taken for granted. This confidence demonstrates that the airworthiness design codes are in good shape.

UK gliders used to be designed to British Civil Airworthiness Requirements (BCAR) Section E - Gliders. This was superseded in the 1960's by the work of OSTIV, which went on to form the basis of Joint Airworthiness Requirements (JAR) Part 22 which was adopted by the EC in the early 1980's. Today virtually all sailplanes, including those from Eastern Bloc countries, are certificated to JAR 22.

Setting a boundary to the problem

The core of any design code is its formulation of a 'design envelope' which specifies a range of flight conditions within which a sailplane can operate AND remain safe and secure.

This envelope is bounded by combinations of airspeeds and load factors ('G') which provides the designer with a closed problem of safety validation. Some boundaries are natural, like stalling, which limit the amount of air load that an airframe can generate on itself. Other limits must be judged on the basis of providing an airworthy vehicle. The most evident limit is that of a maximum speed, in designer's parlance the design dive speed. It is well known that, all other things equal, air loads vary with the square of airspeed, so setting an upper limit on speed goes a long way towards creating a definable problem. Obviously we must provide for adequate maneuver capability at higher speeds but there is some opportunity to optimize the structure if it is accepted the pilot will react to noise and heavy control forces and use only limited control movements when at high speed.

The requirements define design maximum load factors, in both positive and negative senses. For semi aerobatic sailplanes a positive 'g' design limit of around 5 has proved to be adequate for general usage. Higher factors are required for fully aerobatic types. At low speeds it is impossible to achieve such loads since stalling limits the airframe loads, but at higher speeds (above 2-2.5 times level flight stall speed) very high load factors can occur before stalling. At cruise speeds we must choose between a radically over-strength airframe or select a limit load factor boundary above some specified airspeed. To the designer this speed is known as **'maneuver speed'** or to the pilot, as **'rough air speed'**, since below this speed an extreme gust will stall not break the airframe. Additionally requirements stipulate that the airframe should be capable of withstanding full, instantaneous application of any or all controls at this 'maneuver speed'.

If it is not already obvious, these two requirements, in combination offer you, the pilot, a remarkable safeguard:

> BELOW ROUGH AIR SPEED IT IS NOT POSSIBLE TO BREAK YOUR SAILPLANE EITHER BY ENCOUNTERING A GUST (NO MATTER HOW SEVERE, SINCE IT WILL STALL YOU), NOR THROUGH YOUR OWN USE OF WHATEVER COMBINATION OF CONTROL MOVEMENTS.

At the higher design dive speed the limit load factor is normally accepted as somewhat lower (4G in JAR), and only limited control applications (1/3 movement) are catered for. To close the envelope completely similar arguments can be applied to flight under negative G. It is appreciated that high speed, negative G stalls are not everyone's cup of tea! This closed envelope of flight conditions can be characterized by a number of key 'corner points' which will create differing load conditions on all structural components of the airframe.

Where does it hurt (and how much)?

The designer meets his obligations by evaluating the loads experienced by all structural components at all the design envelope's corner points to determine which cases are critical. To do this he will already have had to define the overall configuration of the proposed sailplane to the extent of its external shape, its expected weight and weight distribution (including water ballast if planned). This is the nitty-gritty of design and comes after all the fun bits like picking the best wing section or a new planforms to increase performance.

The work is basically aerodynamic in nature, and a good all round insight is useful in spotting the critical cases. It is worth noting the diverse contributions to such flight loads:

1. Loads required to hold the glider in trim ('Balance' loads).
2. Loads introduced by the pilot through specified combinations of control demand ('Control' loads).
3. Loads created during maneuvers as a result of the distributed mass of the sailplane ('Inertia' loads).
4. Loads imposed on the sailplane when it encounters rough air and turbulence ('Gust' loads).
5. Point loads applied to the sailplane for the outside, e.g. during landing impact, or from tow ropes. ('External' loads).

In some conditions a single contribution can be dominant; for example, wing bending strength is almost invariably designed by the maximum 'G' pull up at maneuver speed. In other situations the various contributions cancel each other out; wing twisting loads are actually reduced as you pull up from a steady high speed condition. The designer is looking for the critical **combinations** of loadings from these various sources to establish which will design any particular structural component.

There are several lessons in this for the average pilot. Firstly, the airframe loads to trim (the 'balance' loads above) are only one part of any critical combination. Thus it is unlikely that a sailplane will fly apart just because you are at a limit condition. On the other hand, it is not unlikely that in gaining **or recovering** from that limit condition some particular component will encounter its critical load combination, particularly in rough air. **For your own part as pilot the best way of reducing this risk is to minimize the not insignificant contribution of control loads (and inertia loads) by handling with care.**

Secondly, the maneuver and gust loads are the only loads which are experienced by the pilot (because they maneuver him too). All other loads are reacted within the airframe and are NOT manifested as 'G' loads. Unless the pilot has specialist knowledge he will not necessarily appreciate these. This has been realized to be a particularly important issue in the recent review of winch launch safety but there are parallels in other flight cases too.

Bend or bust?

Once the critical loads have been determined the glider can be designed in detail. Simple calculations are often used to confirm that a non critical component is well within limits. But for major issues such as wing bending strength the calculation will be carried out with some precision since excessive strength will result in a significant weight penalty. Designers are generally cautious chaps but what about the choice of materials and the construction processes? Is it possible that non conservative assumptions could be undermining our security?

Structural materials vary in their failure characteristics. Under high loading some distort permanently while continuing to function in a degraded manner. Others, albeit equally as strong, fail in a sudden manner without any prior signs of suffering. Crystalline materials such as metals fall into the first category; fibrous materials such as wood or composites into the second. Design practices take this into account. Materials with good yielding properties are required to withstand their critical design load without suffering permanent distortion, the so-called **PROOF** design case. This aspect is usually critical for the majority of metal fittings in a glider. Materials which fail abruptly are required to be exercised to only two thirds of their ultimate fail load within the flight envelope, the so-called **ultimate** case. In cases of new or untried materials special lab tests are required to define which is the critical issue.

With untried materials an extra factor of safety may be demanded; this was the case when GRP gliders were first developed. With experience these factors can be reduced, which is why later generation glass gliders exhibit much greater structural flexibility and lighter weight than earlier designs.

So what does this mean to the pilot?

The good news is that there is conservatism built in at all design stages: your sailplane is **probably** even stronger than the designer thinks. But the message to the pilot here is: **hands off.** These margins, which protect us from design approximations and construction tolerances are designer's and constructor's in-built insurance policy. They are not easily quantified, and may vary with the gliders condition. Exceeding envelope limits is irresponsible and taking serious liberties with the terms under which your sailplane is supplied, quite apart from being personally dangerous. Your insurer might also be interested.

Strength alone is not sufficient

Considerations of structural stiffness are additional to the above. Even given the latest generations of stiffer fibers such as carbon and aramid derivatives, many parts of a modern sailplane's structure are still dominated by stiffness considerations rather than strength. The wide differences in the stiffness characteristics of the various structural materials also complicates matters. Today, not only sailplane wings but all structural elements must possess appropriate stiffness and mass distributions.

The word 'flutter' is often used out of context to describe any form of in-flight vibration. This confusion would not exist if actual flutter were a common experience! Flutter is a mutual resonance between two modes of flexibility which spontaneously occurs once a **critical airspeed** is reached. Most forms of genuine flutter (and there are many), break out with no warning and are extremely destructive. Recent accident investigations involving overspeed cases in FRP sailplanes have always shown evidence of failure induced through flutter. It is likely that once the oscillation has erupted there is little a pilot can do about it. All current requirements demand a safety margin of 25% on the design speed if clearance is sought by calculation alone.

Technology marches on—but at a price.

These days there is a continuous demand for higher performance and better handling qualities, so few stones are left unturned to achieve an edge. In new gliders much of the conventional design conservatism has been removed in a controlled way in the optimized design. This leads to a situation where there are fewer or no 'soft' limits. If you ride beyond those limits you **will** come to harm. Maybe not this weekend but sooner or later.