STATIC LOAD TESTING OF COMPOSITE WING STRUCTURES

1. Definitions

A structure should be designed to be able to withstand limit load without permanent damage or deformation upon unloading.
A structure should be designed to be able to withstand ultimate load without collapse.

The flight envelope of the aircraft gives limit loads at various flight conditions. For normal category aircraft limit manoeuvre load factors of +3.8g, -1.52g are normal. Gust cases may give higher loads. For aerobatic aircraft, limit manoeuvre load factors of +6g, -3g are normal.

Proof load is defined by:

Proof load = limit load x proof factor.

For civil aircraft, the proof factor is generally taken as 1.0; hence proof load testing and limit load testing are one and the same.

Ultimate load is defined by:

Ultimate load = limit load x ultimate factor.

For civil aircraft, the ultimate factor is 1.5.

For both limit and ultimate load testing of composite structures, loads should be multiplied by a special factor that is used to account for reduced strength or stiffness due to manufacturing variability, or degradation of strength or stiffness due to high temperatures or moisture ingress.

For a successful limit load test, a composite structure must carry:

> Limit load x special factor, without permanent damage or deformation upon unloading.

For a successful ultimate load test, a composite structure must carry:

> Limit load x 1.5 x special factor, without collapse.

The CS-VLA requirements give advice on special factors to use when designing and testing composite structures. A typical special factor for a cold-cured white-painted composite structure manufactured in a closely controlled production environment, tested at room temperature would be 1.5. This is made up from multiplying the following factors together:

Temperature factor = 1.25 (white painted structure, room temperature test)
Manufacturing variability factor = 1.20 (closely controlled manufacturing process)
Moisture factor = 1.00 (cold-cured structure)

These factors can be changed to suit a particular test condition. For example, CS-VLA indicates that testing a white painted structure at a temperature of 54°C will reduce the temperature test factor to 1.0. Equally by testing a batch of structures, a reduced manufacturing variability factor can be argued if there is little scatter in the test results from the range of specimens.

2. Purpose of Test

An early decision has to be taken whether to test a component to destruction, or to proof test the structure hopefully without damage or permanent deformation. Thought also have to be given to whether it necessary to test a complete structure to determine the behaviour of a particular component, or whether smaller test specimens can be manufactured to be tested in a simplified manner. Whatever test is to be carried out, it is important to include composite special factors when defining test loads, and to tailor these special factors to the environment in which the test is to be carried out.

For a one-off prototype aircraft, a proof test will usually be called for before the aircraft is flown, unless the structural analysis performed to substantiate the design is sufficient to be able to predict its satisfactory behaviour in service. Clearly, it would be unsatisfactory to ultimate load test a one-off structure because it is likely to be damaged beyond repair. Relying on just a proof test to clear the structure puts onus on the designer to carefully analyse the structure to ensure that it will meet the ultimate design condition without collapse. It would not be acceptable to just proof load and hope for the best as far as the ultimate condition is concerned.

For a kit prototype where a large number of kits are to be built, the investment required to test a sample structure to destruction will be relatively small, and so an ultimate load test will generally be called for in any case.

If the intention when designing a new aircraft is not to carry out structural testing, then the structural analysis work earned out will have to be rigorous. Most designers will welcome the chance to at least proof test a structure to ensure that it will perform adequately in service.

Certainly, if areas of poor structural design are built into the aircraft where sensible analysis is impossible then an ultimate load test will be essential. It therefore follows that if a designer wishes to clear a component without resorting to an ultimate load test, then it must be designed such that it can be effectively analysed and manufactured using materials with known properties.

Thought should be given to the components that need to be tested within the wing structure. The main spar is an important component to test in bending, but a well designed spar is often the most predictable component in a composite wing. Likely to give more potential for trouble are sandwich panel wing skins, and the root-rib where wing torsion is reacted into the fuselage. A test should therefore be selected which will test the wing skins and wing ribs, as well as the wing spar. Additional testing may be required to confirm the strength of control surface attachments.

If the loads in the wing-to-fuselage attachments are difficult to define due to multiple load paths, then it would be sensible to mount the wings on the fuselage and test the wing and the wing-to-fuselage joints.

Certain tests, such as control full and free movement under load, should be carried out at limit load.

Remember to design metallic components to be able to carry limit load x test factor without damage if the composite structure is to be proof tested.

Whether the tests to be carried out are proof tests or ultimate tests, the tests should be carried out with care to try and prevent any early failure becoming catastrophic. By careful load application, it is often possible to highlight structural flaws while leaving the structure basically intact, ready for modification.

3. Loading Calculations

It is conventional to assume the Schrenk spanwise aerodynamic load distribution for wings of typical aspect ratio (say 4 to 8). Care should be taken when more simplified loading assumptions are used to ensure that the loads to be applied are sufficiently severe to ensure a valid test. Particular care should be taken when loading externally braced structures to ensure worst-case loading on whichever part of the structure is likely to be critical.

Apart from the spanwise load distribution, two other parameters need to be fixed for the test. The first will be the chordwise distribution of load. The second will be the angle-of attack at which the wing will be tested.

It will tell the designer the most if the wings are loaded in worst-case torsion. Depending on the location of the wing spar, the worst-case torsion load may be present at high or low angles of attack (aft or forward centre-of-pressure respectively). Thought should be given to the root-rib of the wing. This component is very important in a cantilever wing, because it reacts torsion loads in the wing, and allows them to be carried into the fuselage structure. Therefore, worst-case torsion should also test this important component.

It is important to load the wing at an appropriate angle-of-attack. Generally the worst case in terms of combined lift and drag will be condition A of the flight envelope (high angle-of-attack case).

The worst-case in terms of spar bending loads will usually be condition C or condition D of the flight envelope (gust case and low angle of attack case).

4. Strain Gauges

While not essential, strain gauges positioned at critical locations, if monitored carefully during the test, will give an early indication of likely failure. This is useful from both the safety point of view, and it also gives the opportunity to stop the test and modify if larger strains than expected are experienced.

For example, caution has to be taken if strains in woven glass cloths exceed 0.75%, or glass rovings exceed around 1.3% strain. Caution has to be taken if carbon tows exceed 0.75% strain during test. Above these values, failure is likely, although the precise failure strain will be dependent on many factors.

A common, unexpected, mode of failure during static test is lateral buckling of spar components. Careful monitoring of strain gauges located either side of a spar boom will give an early indication of this problem and the test can be stopped before catastrophic failure occurs.

5. Precautions.

It is most important to proceed cautiously with any load test. Tip jacks. Displacement control.

Position stops next to the structure to ensure failure does not destroy the specimen, plus fuselage.

Upon unloading, it is essential to ensure that the structure has fully settled before going anywhere near it. Contrary to popular opinion, composite structures do not tend to fail suddenly, without some warning. A gradual escalation of damage and delamination can usually be heard before collapse of the structure. It is essential to keep the test area quiet to be able to listen for this escalation of damage.