ESTABLISHING THE STRUCTURAL INTEGRITY OF AGING GLIDERS

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ABSTRACT

The task of verifying the structural integrity becomes increasingly difficult with increasing age of a glider.

A number of factors which influence the static strength are briefly discussed together with the possibility of fatigue becoming a limiting factor on service life.

The procedure of Proof Loading as a means of inspection for structures not prone to fatigue is described. This technique has been adopted by the Gliding Federation of Australia, and a number of old gliders have been permitted to continue flying at reduced placard limits following Proof Loading.

INTRODUCTION

The problem of ascertaining whether a Certificate of Airworthiness should be renewed for an aging glider is eventually faced by every airworthiness authority. Despite the fact that the external appearance may be excellent at the time of inspection, there are a number of factors, some time-dependent, which could have resulted in a reduction in the static strength. These factors include poorly executed repairs and maintenance, fatigue, glue deterioration, degradation of plastics from ultra-violet and the possible effect of heat.

This report is concerned mainly with the approach being adopted by the Gliding Federation of Australia for wooden gliders. At present, all gliders are required to undergo a special inspection as defined in the Manual of Standard Procedures (1) when they reach 20 years, or sooner if decided by an Airworthiness Inspector.

TERMINOLOGY

The terms "limit," "proof," and "ultimate" load will be used in this report, and though they do not have unique definitions, there is general acceptance (2) of the following terms:

1. Limit Load--this is synonymous with Design Limit Load, and is the maximum load that the designer expects the glider to be subjected to during normal service. This load may be experienced more than once by one or more of the type depending upon length and severity of service. Conversely, a little-used glider or one not loaded to capacity may never reach limit load conditions. The application of limit load should not produce any failure or permanent set in the primary structure. Furthermore, any distortion of secondary structure at Limit Load should not adversely affect the flying capabilities of the glider.

2. Proof Load--this can be either equal to or greater than Limit Load, but in the case of the complete structure it is in most instances taken as being equal in magnitude.

3. Ultimate Load--this is the maximum load that the glider structure must withstand without complete collapse.

Ultimate Load in most cases is required to be 150 percent of Limit Load. In a structure designed for static strength only, the stresses should reach failing stress values at Ultimate Load conditions.

DURABILITY

The durability of a glider is difficult to ascertain without actually operating it for a large number of years.

Wooden Airframes

As far as is known wood has an infinite life and the life of the structure is governed by the bonding agent, i.e., the glue. Some years ago, there were doubts as to the life of some of the urea and phenol formaldehyde glues used in aircraft production. However, as a result of a very extensive investigation in Australia and England, it was established that the glues commonly used showed little deterioration in periods of up to 25 years.

Furthermore, there is evidence (not widely spread) from two independent structural test investigations that have produced confirmation of the satisfactory durability of phenol-type adhesives. A number of locally produced Grunau glider wings were tested to destruction, by the Aeronautical Research Institute, Argentina, after 15 years of club use and all failures occurred in the wood.

During an investigation into the fatigue characteristics of Vampire wings at the Aeronautical Research Laboratories, Australia, involving testing to failure of 19 complete wings, two fuselages were used to react the loads, and these survived the entire program with no sign of failure in either the wood or the glued joints.

The durability of glues used in glider construction has been reported by Irving and Vernon (3). The British Gliding Association has also made a study of the airworthiness of aging wooden gliders and has concluded that with correct maintenance and regular inspection, they should have an operating life of at least 20 years (4). The oldest glider still flying in Australia (the Golden Eagle, designed by H. G. Richardson) was constructed in 1934 using casein glue. According to the Council for Scientific and Industrial Research Organization (CSIRO) this glue has a life of at least 50 years provided adequate sealing precautions are taken to prevent an excessive ingress of moisture.

Metal Airframes

Metal aircraft structures have proven themselves as far as durability is concerned, although in the case of gliders denting of the wing surfaces cannot be tolerated because of the adverse effect of performance. Increasing the drag by a pound or so does not usually concern the powered aircraft operator.

Plastics

The durability of fibre reinforced plastic (FRP) structures is yet to be established. During manufacture a special ultra-violet shielding layer is incorporated in order to block out sun rays that might degrade the resin. From the experience of fibreglass boats there is reason to suspect that there probably could be degradation after about 10 years of service.

FATIGUE

Fatigue in Wood Structures

The safe fatigue life of wooden gliders designed to the British Civil Airworthiness requirements Section E--Cloud Flying Category--has been estimated by Obee (5) to be 100,000 hr which, for all practical purposes, can be regarded as infinite.

Fatigue in Metal Structures

The problem of fatigue is now well known to designers and operators of all metal aircraft. Glider owners have been spared this worry because of the low design and operating stresses in the structure and the small number of hours flown. However, the demands of high performance have resulted in a raising of stress levels and a very significant increase in the number of hours flown each year.

A preliminary analysis of some data shows that significant amounts of fatigue damage can be received by a metal glider during its effective service life. Flight load measurements have indicated that the amount of "g" being applied is perhaps higher than was expected during the design stage. The design maneuvering limit load factor of 5.3 has been considered to be adequate, based on previous experience. However, some "g" load measurements made in Russia and presented in Ref. 6 have indicated that it is essential for pilots to be trained not to overload their gliders. The data is summarized and illustrated in Fig. 1. By comparing the design load factors given in Ref. 7 with this loading spectrum, it can be seen that the proof load was being exceeded once every 100 hr until pilot techniques were improved. In the 51 hr of later recording the highest level recorded was 4 g. However, this sample is rather small, and it is possible that the load levels could be somewhat higher in a longer period of recording.

Preliminary fatigue life estimates for an aluminum alloy structure based on the Russian loading data and fatigue damage hypothesis, according to Payne (8), have indicated that an investigation should be made into stresses on the tension surface and further load data obtained, in order that a more accurate calculation may be made.

Fatigue in FRP Structures

All FRP glider structures designed in Germany and Switzerland are subjected to a programmed loading sequence fatigue test as part of the Certification procedures. If only one specimen is tested, a scatter factor of at least 3 is applied to the test life in order to obtain the safe operational life of the glider. The operational life of a glider has been assumed to be 3000 hr which allows for 200 hr of flying annually in a period of 15 years. It has been further proposed that should the structure successfully reach 9000 hr on test and, at the completion of fatigue test, withstood an application of ultimate load, then the operational life will not be restricted.

Fatigue of Structures

The problem with the effect of fatigue in a glider structure is that there is no reduction in the static strength until a crack appears, although this depends on the stress level and whether the material fails in a brittle manner. Cracking that is categorized as being easily detectable can be regarded as having a length of at least 0.25 in. (6 mm.) and in a lightly stressed area, it can even be as long as 2 in. (5 cm). The likelihood of fatigue becoming a problem during the service life of a glider is dependent on the stress level and the number of applications. Table 1 gives some of the relevant properties of materials commonly used in glider structures and a measure of fatigue resistance is the ratio of the alternating stress for a life of 10 million cycles to failure and the ultimate strength of the material.

AUSTRALIAN GLIDER AIRWORTHINESS SYSTEM

The overall responsibility for Civil Aviation in Australia rests with the Director General of the Department of Civil Aviation. However, he has delegated the responsibility for the airworthiness of gliders to the Gliding Federation of Australia as illustrated in Fig. 2. The Department has retained the responsibility for the approval of new types of gliders, and when the type approval has been granted, they become the responsibility of the Federation. The Federation registers all gliders, but does not handle the inspection or issue of airworthiness certificates for Developmental Gliders. Recently, the Federation requested that the Department make the first issue of airworthiness certificates to gliders that are commercially imported. In effect, the Federation accepts the delegated responsibility for all gliders operated by its members. To implement these responsibilities, the Federation has a number of officers with clearly defined tasks as illustrated in Fig. 3. All of these officers act in a honorary capacity and, of course, undertake all the associated tasks in their spare time. Some of the activities are part of the normal club operations.

ADDITIONAL "INSPECTIONS" FOR OLD GLIDERS

Additional work to be undertaken arising out of a 20-year inspection on a glider is decided between the airworthiness inspector making the inspection and the regional technical officer for airworthiness. The Federation has also appointed a number of senior inspectors who are authorized to supervise any further action. The decision to take further action is based upon the visual inspection,

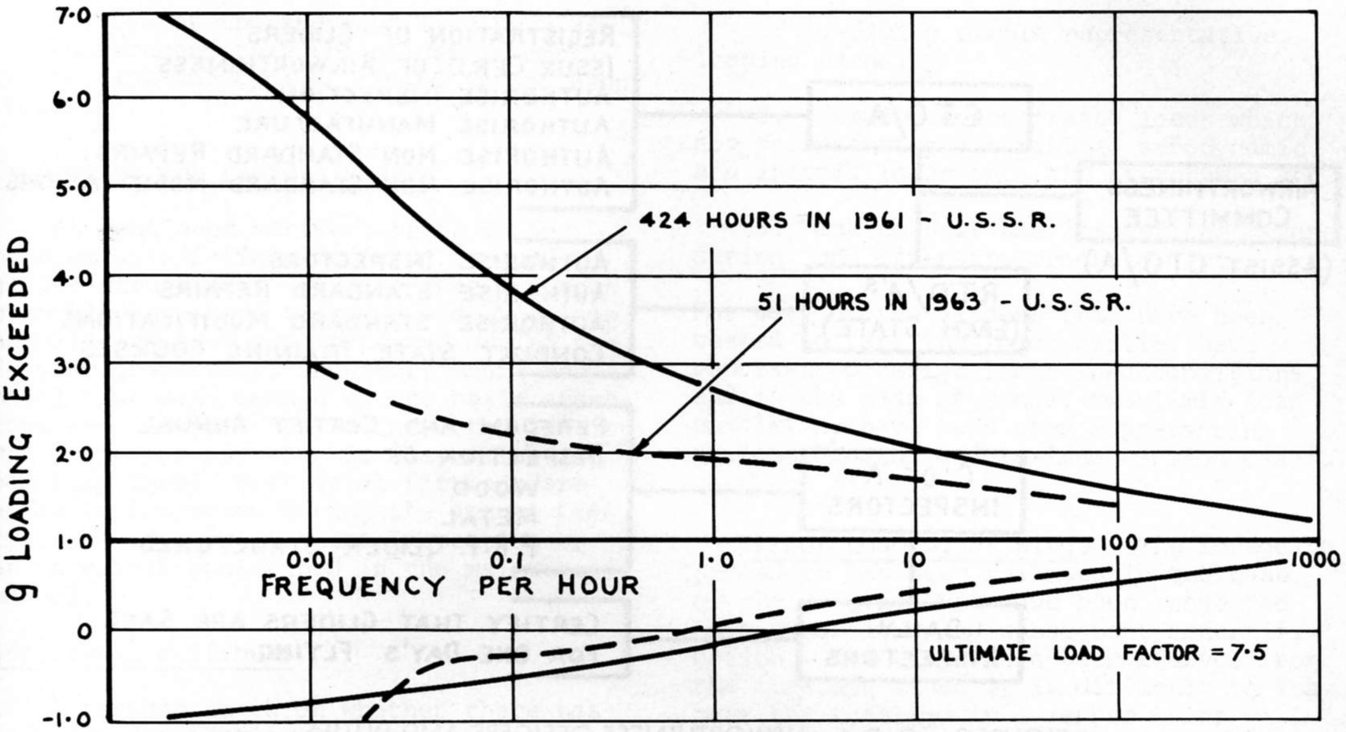

FIGURE 1. LOADING SPECTRUM GUST AND MANEUVER--BLANIK GLIDER

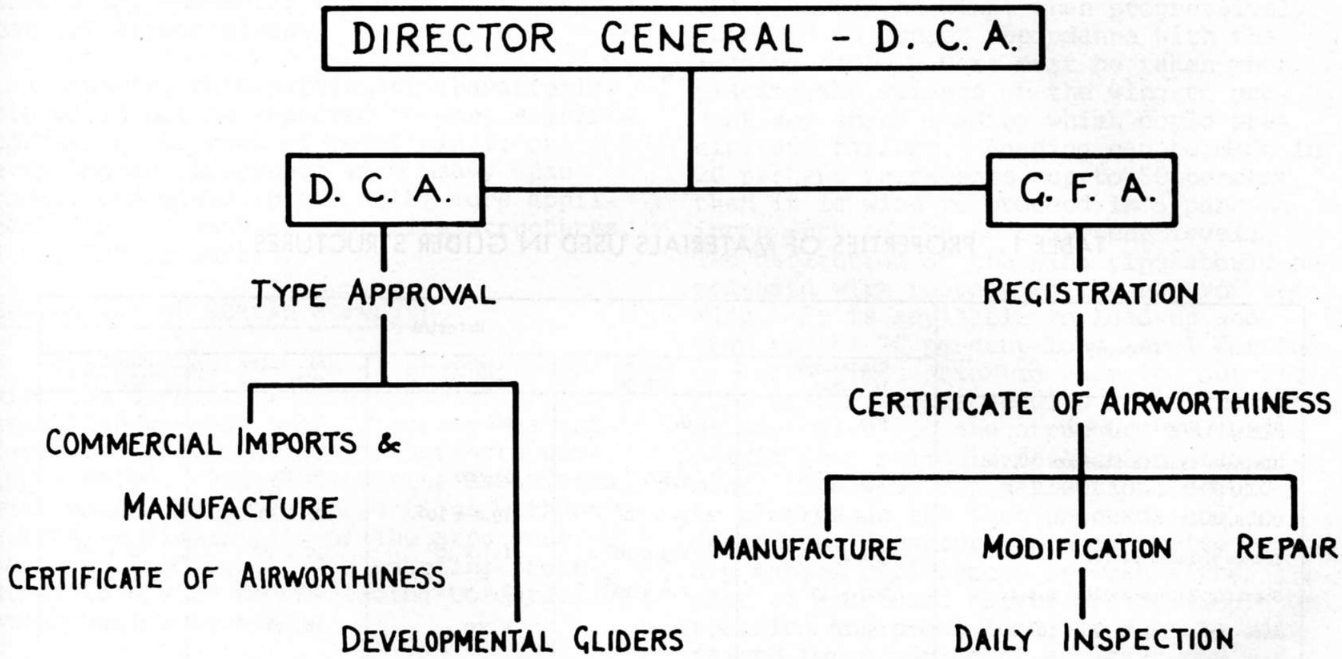

FIGURE 2. GLIDER AIRWORTHINESS RESPONSIBILITY CHART

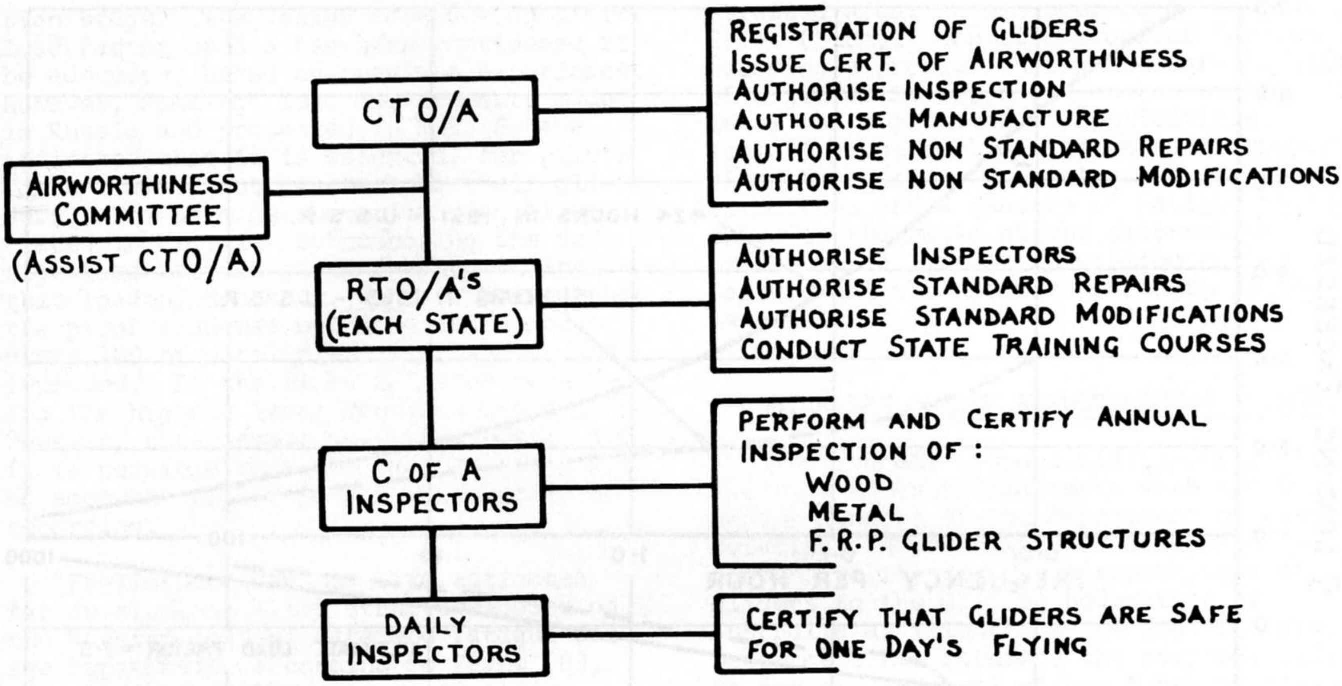

FIGURE 3. G.F.A. AIRWORTHINESS OFFICERS AND DUTIES

TABLE 1. PROPERTIES OF MATERIALS USED IN GLIDER STRUCTURES

Property	Material				
	Glass/Epoxy Laminate	Spruce DTD 36	Oregon DTD 469	Al. Alloy 2024	Steel SAE 4130
Specific Gravity (S.G.)	1.7	0.5	0.6	2.8	7.8
Ultimate Tensile Strength (U.T.S.) - p.s.i.	57,000	9,500	11,500	70,000	180,000
U.T.S./S.G.	33.6×10^3	19×10^3	19.2×10^3	25×10^3	23×10^3
Youngs Modulus p.s.i.	3×10^6	1.3×10^6	1.7×10^6	10×10^6	30×10^6
Specific Youngs Modulus p.s.i.	1.7×10^6	2.6×10^6	2.8×10^6	3.6×10^6	3.9×10^6
Alt. Stress for Life of 10^7 Cycles	15,600	5,000	5,000	18,000	70,000
$\frac{\text{Alt. Stress for } 10^7 \text{ Cycles}}{\text{U.T.S.}} \times 100$	27.4%	52.6%	43.5%	25.8%	38.9%

a knowledge of the previous life such as the environment that the glider is operated in, and the type of flying it had been receiving.

Inspection for Fatigue Cracks

As mentioned earlier, there is no problem with fatigue failures in wooden glider structures. Fatigue cracking does occur in the steel fittings and these are normally removed and inspected during the 20-year inspection. However, where removal may cause damage to the basic structure and the part can be inspected in situ, the inspector may use his discretion in removing them. Most metal fittings are normally inspected during the annual Certificate of Airworthiness Inspection or at intervals prescribed in the maintenance manual.

Structural Stiffness

A further check on whether there has been any degradation in wing structures is to measure the resonant frequency in a primary bending mode.

Some manufacturers, particularly in Germany, require that this check be conducted during each annual inspection. The frequency of the wing at time of manufacture being quoted in the original Certificate of Airworthiness.

However, this particular characteristic would not be expected to vary significantly in the case of metal wings, or even wooden structures with heavy spar booms, and would appear to be more applicable in the case of composite structures, i.e., FRP gliders.

Evaluation of Static Strength

The primary concern of an inspector with the durability of a structure is to establish whether that structure has suffered a decrease of static strength during service. The difficulties associated with making adequate inspections without extensive dismantling of the structure have resulted in the GFA adopting procedures involving proof loading to establish structural integrity.

Determination of Proof Loads. In arriving at the proof loading tests required for establishing structural integrity, there are numerous difficulties such as

1. deriving simple representative loading cases;

2. feeding concentrated loads which are representing distributed aerodynamic and inertia loads into the structure; and

3. making suitable inspections before, during, and after the proof loading.

For each of the gliders that have been tested so far, the loads applied have represented design limit load conditions and in the case of wings, two limit load conditions have been used representing maximum bending and maximum torsion cases.

Proof Loading of Wings. The foregoing procedure has been followed in the case of the gliders that have been subjected to a proof load and subsequent recertification. The wings have been removed from the fuselage since it is difficult to support the fuselage in a manner which will not result in it being damaged. A simple dummy fuselage has been constructed to support the wings in an inverted position for ease of loading. Plywood has been placed over the fabric-covered regions to enable sand bags or lead shot bags to be loaded on to the wing. During the actual loading, the bags are placed firstly at the root of the wing, then progressively outboard in strict accordance with the loading table. Care must be taken when placing the weights on the wing to prevent any shock loading which could precipitate failure. Loading can be made in 20 percent increments, up to 50 percent, then it is wise to proceed in 5 percent increments to the 66.6 percent level. The deflection of the wing tips should be measured with respect to the root of the wing. It is advisable to load up and down to the 20 percent load level for two or three times prior to carrying out the test proper. This results in taking up of any "give" in the structure and will result in a reliable deflection measurement. The wing tip deflections should be plotted as the test proceeds and so detect any departure from linearity or any marked differences between either the port or starboard halves of the wing. On reaching the proof load, it must be maintained for a period of at least two minutes, during which time no appreciable creeping of the structure should occur (less than 0.1 in. or 2.5 mm). On removal of the load, the structure should be left for a period of at least 20 minutes before checking the amount of permanent set. This is because of the very slow rate of recovery of the load and an erroneous answer could be obtained by taking the deflection reading immediately upon removal of the load.

Proof Loading of Empennage. The loading of the tail plane and/or fin presents a simpler problem as both these can be loaded while still attached to the fuselage. In fact, it is most desirable to load the tailplane while attached to the fuselage for two reasons: first, it is difficult to construct a dummy fuselage of identical stiffness, and second, it enables the strength of the fuselage structure to be checked at the same time.

The critical loading case will most likely be an asymmetrical condition, and it will be found possible to reproduce the distributed loading with a single load. The loading station must be capable of withstanding the shear load and to assist the tailplane structure, the load should be applied to a profile board lined with felt and clamped around the tail plane. One method of loading would be to use a spring balance loaded with a chain hoist or a set of pulleys. The requirements regarding care in loading and taking deflection measurements are similar to those for the wing.

Observations During Test. During the proof loading tests certain data may be obtained and events observed which will assist the inspector in making an assessment of the structure. These include:

1. strain in both local and overall situations and this should remain linear up to the maximum load applied;

2. buckling of panels which should be confined within stringer, rib, and spar boundaries. Judgment is necessary as to whether there is any likelihood of instability occurring before ultimate load is reached;

3. Permanent set after removal of load; the amount of permanent set should not exceed 5 percent of the deflection at proof load.

Validity of Proof Loading

This approach to strength justification is, however, only valid for structures manufactured from materials whose physical properties do not deteriorate over the predicted range of operating temperatures. When material properties are reduced by temperature effects, for example, FRP structures in tropical climates, then a proof test at room temperature may fail to achieve design limit stress conditions. In such instances, the test cannot be defined as a proof test to establish a margin of safety over a normal operating condition. Cooling or heating of a complete glider structure should not present any difficulties to the structural test engineer. Convection heating and cooling techniques have advanced rapidly in recent years through the development of equipment required for the study of thermal stresses induced during transient conditions in aircraft structures.

Release After Proof Load Testing

A successful proof loading test does not prove that the glider structure is capable of withstanding the designed ultimate failing load, but from its behavior during loading reliable indications of its integrity can be obtained. The glider can only be released for lower than normal operating placard limits, for example, no aerobatics permitted and a reduction in both the rough gust and smooth air maximum air speeds. The glider is then being operated with a known safety margin beyond the maximum expected service stresses.

G.F.A. EXPERIENCE

A total of six glider wings and one tailplane have been successfully subjected to proof loading tests as part of the inspection for renewal of the Certificate of Airworthiness.

The majority of these tests have been conducted by club members supervised by the G.F.A. Regional Technical Officer for Airworthiness.

Almost without exception there have been no observations which would indicate any deterioration in the strength of the structure. In other words, each of the structures had behaved as if it still possessed the strength required by the original design.

In one instance, a dubious repair in an aileron spar failed, and in another case, a failure occurred in secondary structure which was ascertained to be a design deficiency.

Proof loading has not been confined to old glider structures, and in fact has been used to check a wing apparently undamaged in an accident which demolished the fuselage. The inspector's findings were confirmed by the test which saved cutting access holes in a sandwich structure.

The technique was also applied to a new glider wing which had been constructed by club members over a period of 15 years. The test was conducted in order to establish complete confidence in some of the design assumptions, and the ability of the constructors; it was not mandatory as far as certification was concerned (9).

Each of the old gliders tested had been designed in accordance with the B.C.A.R. semi-acrobatic category (now designated cloud flying category) and after the test has been downgraded to normal category. All except one are currently flying, and their next proof test is not proposed until they have completed a further 15 years of flying, unless an inspector declares otherwise.

DISCUSSION

Fatigue Damage

The amount of fatigue damage accumulated by glider structures can be expected to reach significant levels in the near future.

This arises from the higher stresses in the present generation of glider structures and the large number of hours being flown (instances of gliders flying 1000 hr per year are recorded) involving flight near the limits of the flight load envelope.

Airworthiness authorities may be required to examine the matter of fatigue life estimation and flight load measurements in more detail, if the present level of structural reliability is to be maintained.

In aeroplane structures, the designer attempts to produce a fail-safe structure, which allows fatigue cracks to propagate to an easily detectable length before there is any significant drop in static strength. However, this is not always possible, and in the case of single load paths, the structural element must be regarded as a safe life component having a calculated safe service life.

Most glider structures fall into this latter category particularly in the region of the attachment of the wing to the fuselage.

Proof Loading

For structures made from materials resistant to fatigue or having a very long life, an application of the design limit load can be used as a method of proof loading the structure.

The Gliding Federation of Australia has successfully adopted this technique for establishing the structural integrity of aging gliders.

The task of applying representative loads to a glider structure is within the capability of club members, providing supervision by a suitable qualified airworthiness inspector is available.

Since the proof loading cannot demonstrate an adequate margin of safety over the original placard limits, the glider can only be released for lower limits.

There does not appear to be any reason why proof loading cannot be applied repeatedly and the glider permitted to fly for a further period if it successfully passes the test.

The oldest glider flying in Australia is now 36 years old and shows no sign of deterioration in static strength. There are a number in excess of 20 years still being regularly flown in normal club operations.

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A LOW SPEED SAILPLANE FOR RESEARCH

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A few years ago we entered into a research project at Vanderbilt University to study the flight characteristics of several species of gliding birds, namely the Black Vulture, Turkey Vulture, Red Tailed Hawk, etc.

A portion of the flight measurement was done by following a free-flying bird in a quiescent atmosphere with a sailplane. The altitude and velocity of the bird were matched at frequent intervals by the sailplane and reported to the ground recorder via radio. Analysis of the data collected by many flights provided the information required to plot the polar diagram of velocity versus sinking speed for the bird. This method proved to be successful and reliable, however it was limited by the fact that the stalling speed of the sailplane, namely 30 mph, was so high that only the high-speed portion of the bird's polar diagram could be measured. The sailplane which is the subject of this paper was designed to more nearly match the speed range of the bird. Flight tests to date indicate that this goal has been achieved.

The original primary design specification for the subject sailplane was a stalling speed of 20 mph. In addition, the flight performance was to be at least equal to that of the birds we were measuring and a load factor of 6 was to be main-