The Durability of Glues Used in Glider Construction

by F. G. Irving and C. O. Vernon
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Summary
The Australian D.C.A. and to a less extent the U.K. A.R.B. introduced operational restrictions in 1963 on many types of powered wooden aircraft having stressed-skin construction, owing largely though not entirely to an apparently serious deterioration in the glues used for assembly, the D.C.A. finally withdrawing the Cs. of A. altogether. The background paper to the D.C.A. action hinted strongly that gliders of similar construction should be lifed at ten years.

One of the reasons for the action taken lay in the results of some glue tests carried out in accordance with B.S. 1203 and 1204 by Forest Products Research Laboratory and quoted in their Bulletin 38 (Second edition), and in particular the data given in the summary table of that report. The table indicated that urea-formaldehyde (U.F.) glues could lose up to 60% of their initial strength after ten years. From this it has been inferred by some that the U.F. glues used in aircraft assembly could suffer such deterioration. As the following paragraph illustrates, this is not necessarily the case.

Taken out of context, the table in question can be grossly misleading. It is an overall summary of the complete set of tests made, covering a random selection of glues and hardeners from those available at the time. To find the test data for the U.F. glue used for the majority of gliders built in U.K. since World War II, viz. Aerolite 300, it is necessary to turn to another more detailed report and to identify the code references used therein for this particular glue. The figures so revealed show 20% loss at 15 years on specimens stored in good conditions and 40% at 10 years on those stored in high humidity; in no case did the strength fall below specification by more than 12%. When the test results are compared with the values that would correspond to those normally assumed for stressing purposes, bearing in mind the differences between test specimens and actual aircraft joints, the loss with time is not significant.

Additional tests made by CIBA (A.R.L.) Ltd., the makers of Aerolite 300, at various periods up to almost 20 years, and by Slingsby Sailplanes Ltd. on test pieces of a different type at periods up to 14½ years, support the latter conclusion.

Tests made by Forest Products on casein and on resorcinal-formaldehyde at 10 years, and by Slingsby Sailplanes Ltd. on Beetle A and Mouldrite (two other early U.F. glues which have not been used in aircraft construction since 1945) at 17 years, were equally satisfactory.

Experience of glues on gliders in service – the other real test – has, as far as the U.K. is concerned, been very satisfactory. Of the hundred or so gliders likely to have been scrapped on account of glue deterioration, the poor condition being in all known cases very obvious, all except three were of casein, the odd three being of foreign origin and built with an unknown glue which may have been a U.F.; as far as is known none was assembled with Aerolite 300 or with any other British U.F. glue. Strip reports compiled in the course of major overhauls, on U.F.-built gliders up to 17 years old, and on casein-built gliders up to 26 years old, have in general revealed only minor defects. Only with casein has the primary structure been affected at all; the number of cases was small and the defects were local and confined to places subject to moisture ingress.

It is concluded that glued joints on gliders in U.K. operation have not been responsible for any reduction in airworthiness beyond the point for which current inspection procedure is adequate, and that there is no case for setting any life for gliders built with any of the above-named glues, subject to reasonable storage and to proper maintenance and inspection. With casein the latter requirements are particularly important.

1. Introduction
The airworthiness of wooden aircraft, particularly those with stressed skin construction and/or closed box spars has been a source of concern to some airworthiness authorities over a considerable period. In particular, the U.K. Air Registration Board (A.R.B.) and the Australian Directorate of Civil Aviation (D.C.A.) acting on more or less parallel lines, have issued various documents advising and instructing inspectors and owners (Refs. 1 to 5). In Australia, the D.C.A. severely restricted the operation of ten types of powered aircraft in 1963, and withdrew their Certificate of Airworthiness altogether at the end of that year. In U.K. the A.R.B. issued rather less severe restrictions in respect of some 28 types, together with recommendations for flight limitations aimed at maintaining flight loads substantially below design values; these restrictions and limitations were designed to allow the aircraft concerned to complete their useful lives while at the same time limiting the risk associated with possible deterioration of the structure.

A major factor influencing the authorities, though not the only one, was the alleged high deterioration of glues, particularly urea-fomaldehydes. All the aircraft concerned in the actions taken so far are powered types, many of considerable age. The A.R.B. have made no suggestions for corresponding restrictions on gliders, but in Australia Langford and O'Brien in ref. 9 specifically state in heavy type, in relation to owners of gliders of stressed ply-shell construction—"They should give serious thought to ceasing to fly after ten years any gliders using synthetic resin in their construction."

If gliders were really subject to such effects to the implied extent the consequences to the sport would be catastrophic. The purpose of this paper is to examine the technical facts of the matter, to show that some of these when taken out of context can be grossly misleading, and to consider other evidence specifically applicable to gliders and the types of glue used in their construction.

Inasmuch as the data examined do not cover duty cycles of temperature and moisture, the conclusions drawn must at present be considered to be restricted to temperate conditions.

2. Types of Glue used in Glider Construction

The glues used in the manufacture of aircraft plywood, since well before World War II, are hot—setting phenolic—resins, the durability of which has never been in question. There is unlikely to be any glider on the B.G.A. register currently flying—the earliest was constructed in 1933—which does not use such plywood. The present concern does not therefore involve plywood, but is confined to assembly work.

For the latter purpose, the glue most generally used before the war was casein and a number of casein-built gliders are still in service. Its use on powered aircraft continued up to about 1942. From then onwards there was a change to urea-formaldehyde (U.F.) synthetic glues. The earliest U.F.'s were the German Kaurit W and its U.K. counterpart Beetle W, but these were soon replaced by Beetle A. The properties of these varied somewhat as a variety of hardeners was used. Since 1946 the glue most used has been Aerolite 300. A few made with Beetle A and Kaurit are however in existence. More recently another type of synthetic glue, resorcinol-formaldehyde (R.F.) has been used. Experience of this in gliders is as yet small, but there is reason to believe that it may prove superior to U.F. types in respect of durability.

We are accordingly concerned with all these glues. Inasmuch as the majority of gliders now flying in the U.K. have been assembled with Aerolite 300, this glue is of greatest interest. Because of the age of surviving pre-war machines, however, casein is also still of considerable importance. In this paper, therefore, most emphasis is placed on these particular glues.

3. Urea-Formaldehyde Glues

Forest Products Research Laboratory, of Princes Risborough, England, has carried out periodic tests on plywood, close-contact, and gap joints of the types specified in B.S. 1203 and 1204, made with glues current in 1942 to 1947. The following table, taken from p. 18 of F.P.R. Bulletin 38 (second edition ref. 6) summarises the results for gap-joint specimens stored indoors at 25°C and 60% relative humidity.

Types of Glue *	Per cent failing load retained: Mean	Range
P.F. at 145°C, R.F., U.F., at 100°C. casein and animal	90	70–100
Cold Setting P.F.	80	60–95
Cold Setting U.F.	65	40–95

* Types of glue are denoted by the following abbreviations:
P.F. Phenol-formaldehyde resin.
R.F. Resorcinol-formaldehyde resin.
U.F. Urea-formaldehyde resin.

The above table has been widely quoted as evidence of the proneness of U.F. glues in general to time-deterioration. Taken out of context, this would appear to be so, and since Aerolite 300 is a U.F. glue one would be temped to infer from these figures that it is likely to be very unsatisfactory as an adhesive for aircraft. Indeed Ref. 9, which gives the background to the D.C.A. action, stated that "very little extrapolation is necessary to show that the 1.5 safety factor used in aeroplane structural design can readily be consumed by this natural strength lapse with time".

In point of fact, this is not a valid deduction from the test data at all. In the first place, Bulletin 38 clearly says "The adhesives used in these tests were taken at random from those available to the Laboratory ten years or more ago for the purpose of assessing the ageing characteristics of the types in their widest sense. The glues were not necessarily recommended by their makers as having the property in question." Secondly, specific brands of glue are not identified. Thus in reality the test data simply show that **some** U.F. glues may lose up to 60% strength after ten years, in the conditions mentioned, without indicating which. They equally well show that others may only lose 5%.

It is in fact known that many of the early U.F.'s were used only for a short period, while others among those tested were purely experimental. A few aircraft are likely to have been built with the poorer glues; as far as gliders are concerned, the use of glues which may have been in the doubtful category was confined to periods totalling a few months, all prior to 1946.

In the third edition of Bulletin 38 (ref. 7) an extended table is given covering tests over a longer period; the following is an extract of that part dealing with cold-setting U.F.'s.

	5 years: No. of glues	5 years: Range	10-12 years: No. of glues	10-12 years: Range	13-15 years: No. of glues	13-15 years: Range	19 years: No. of glues	19 years: Range
Gap	21	60–100	17	40–95	25	40–90	—	—
Close-fitting	12	60–85	18	40–85	11	35–90	2	70–100

Range = min. and max. % of initial joint strength retained.

In commenting on the table we cannot do better than quote from the text of this edition: "The purpose of giving the range rather than the mean is to show how both the best and the worst brand of the particular type of glue can perform. This presentation emphasises for example, that whilst the best U.F.'s have ageing characteristics as good as any other type, the worse of those tested was consistently below the minimum for other types."

The results also show that at least one glue was as good as new after 19 years.

Clearly, to condemn U.F. glues as a class on the basis of generalised figures such as those given above is grossly misleading and quite unjustifiable.

The evidence for some specific glues, Aerolite 300, Beetle A, and Mouldrite, will now be examined.

3.1. Aerolite 300

3.1.1. Forest Products Research Laboratory Tests

The detailed tests, on which the broad summary given in the table above is based, are to be found in Ref. 8. In that report, propietary names of glues are not given, but each is identified by a code reference. The code numbers for Aerolite 300 are L131 (Aug. 1942), L171/L172 (Feb. 1943), L430 (Nov. 1944) and L498/L499 (Aug. 1945). The individual results for these are tabulated below. In each case, the figures relate to mean vales for twelve test pieces. Percent strength is defined as

$$\frac{\text{Failing load of specimens at stated time}}{\text{Initial failing load of similar specimens}} \times 100$$

The percentage strengths were:

Type	Storage Conditions	Man'd.	Initial Failing Load lb	Time Years	% Str.
Close contact	Indoors at 25°C and 60% R.H.	1944	875	5 10	80 60
	In box in open field	1945	850	5 10	95 70
	Centrally heated shop	1945	850	12	75
Gap	Indoors at 25°C and 60% R.H.	1943	610	5	100
	In box in open field	1945	565	10	100
	Centrally heated shop	1945	565	12	95
		1943	595	14	70
		1942	615	15	80

The specification requirement of B.S. 1204 for close-contact joints is 600 lb. for a mean of six and that for gap joints is 450 lb. The only cases in which the loads were below specification were (a) close-contact joints at high humidity and temperature at 10 years (12% below) and (b) gap joints in centrally-heated shop at 14 years (8% below).

It may be concluded that the durability of these early Aerolites was very good, the loss of strength over the period of the tests being insignificant. Later versions have been slightly refined and may be expected to be, if anything, better.

Even more interesting than the figures themselves, is the fact that no Aerolite 300 gap-joint results are given for indoor conditions at ten years, and hence the overall figures for U.F. glues quoted in Bulletin 38, (second edition) which do refer to such joints, conditions and period, cannot relate to Aerolite 300.

3.1.2. CIBA (A.R.L.) LTD.

CIBA (A.R.L.) LTD., have made numerous tests. One series on specimens stored under good, but not precisely regulated, indoor conditions gave the following results:

Type of Joint	Close	Gap	Gap	Close	Gap
Hardener	G.B.P.	G.B.M.	G.B.M.	G.B.Q.	G.B.Q.
Specimens made	21. 1. 49	31. 8. 44	15. 7. 43	31. 8. 43	31. 8. 43
Number of specimens	6	6	6	3	3
Initial failing load, lb.	825	520	600	—	—
Date of Test ...	20. 7. 60	20. 7. 60	20. 7. 60	23. 5. 63	23. 5. 63
Age of Test, years	11½	16	17	19¾	19¾
Final failing load, lb.	765	550	535	760	555

The specification figures of 600 lb. for close-fitting joints and 450 lb. for gap-joints were thus exceeded in all cases, and the results are highly satisfactory. To quote the manufacturers, "The tests show no evidence of a loss of strength due solely to the passage of time. Some sets of joints actually showed an increase in strength compared with those initially recorded".

The percentage of wood failure in the "gap" specimens was somewhat inconsistent. The worst case related to the third column of figures, where the initial percentage of wood failure was 50% and the final value 25%. (Again, these are mean values for 6 specimens.) In the case of the close joints, there was 100% wood failure in the final tests of 20. 7. 60 and 80% in the tests of 23. 5. 63. In the former case, the initial tests gave a 30% wood failure. As these figures imply, and the details of the tests indicate it quite strikingly, there seems to be no correlation between percentage wood failure and failing load. This could be a consequence of using timber whose strength under the test conditions, was closely comparable with that of the glue. Another series using G.B.Q. hardener started more recently, stored at 70°C and 20% relative humidity, yielded the following:

Type of joint:	Close	Gap
Initial strength, lb.	700	530
1 month	660	495
6 months	730	450
1 year	730	510
2 years	655	440
4 years	650	450
Control (2 years at room temperature)	780	575

The conditions for these tests are a good deal more severe than those likely to occur in aircraft components in temperate climates. The figures shew that even in such conditions deterioration is small, and while it is too early to draw a firm inference concerning the durability in more adverse climates the results as far as they go are very encouraging.

3.1.3. Slingsby Sailplanes Ltd., Tests

Slingsby Sailplanes Ltd., have tested 61 Aerolite 300 specimens taken from actual glider components up to 14½ years old. Each sample was sawn out and then built up with additional blocks to make a one-inch-cube specimen with the glue line to be tested running along a plane of symmetry parallel to one face. The glue area was nominally one square inch. The components from which the specimens were taken had mostly been stored in good, but not precisely regulated conditions. The results of these tests are tabulated below. Since the glue area varied appreciably from the nominal value, the results are expressed as mean strength, obtained by dividing the failing load by the actual area of the specimen. The figures may also be thought of as corrected failing loads—corrected, that is, to the nominal area on a proportional basis. In the table, each column gives the mean result for a batch of specimens tested at a particular time.

Age (years)	5	11½	12	12¼	14¼	14½
No. of specimens	4	14	4	8	17	2
No. of components	1	4	1	2	3	1
Mean strength p.s.i.	1620	1185	1490	1280	1235	1210

In considering these data it must first be noted that there was a wide variation in the number of specimens in each batch, and that in three of the batches all specimens came from single components. Some specimens were spruce/spruce joints, others were plywood/spruce; for example, all four 5-year specimens came from a Skylark 3F nose-rib, and the results would not be expected to be exactly comparable with those of the specimens aged 11½ years, which came from Kite 2 fuselage frames. Secondly, while many components were remarkably consistent, there was in some cases quite a variation of strength among different specimens taken from a single component. Fully detailed results are not given here, but a Motor Tutor frame gave figures from 575 to 1155 p.s.i. for example (we are considering this machine as a glider in the present context); a rib from the same machine gave from 755 to 1505 p.s.i. Some of the variation is probably genuine (one would hardly expect complete uniformity over a component line a fuselage frame), some will result from differences in shape and nature between one specimen and another, and only part is likely to be due to ageing effects.

Since the test specimens were different from those prescribed in BS 1204, though of similar if not precisely equal glue area, the figures considered as corrected failing loads are not directly comparable with those quoted in 3.1.1. and 3.1.2. above or with the specification minimum of 600 lb. This is because the strength of a joint is dependant on its shape and on the properties of the adherends as well as on those of the glue. Thus for stressing on a simple "apparent mean stress" basis ample margin must be allowed between the permissible values taken for design purposes and results achieved in tests on either standard specimens or those representative only in limited degree. Slingsby's current design maxima are:

Basic values.	450–200 p.s.i.	according to
Web/flange joints in spars .	340–150 p.s.i.	grain/load
Ply biscuits	160– 70 p.s.i.	angle.

Bearing these cautionary remarks in mind, it is nevertheless interesting to note that only three of the component specimens gave loads lower than BS 1204 minimum and only one an apparent mean stress (340 p.s.i.) within the above design range, although even this was above the 230 p.s.i. maximum in use at the time at which the particular components were produced. This individual case concerned a component not of Slingsby manufacture, and it is suspected that unsanded ply was used. The latter probably applies in a few other cases also.

Clearly it is impossible from these tests to draw precise conclusions on the effects of age, but there seems little indication of any general deterioration reaching a serious extent in the period they covered.

3.2. Beetle A

Little test evidence on this is known to the authors. Fourteen glider-component specimens, similar to those described in 3.1.3. above, have been tested by Slingsby Sailplanes Ltd. All were taken from Frame 5 of a Kite 1, and all were tested at 17 years.

Three specimens failed at mean stresses of 370, 715 and 920 p.s.i. respectively, and the remainder at between 1150 and 1465 p.s.i. The average of the latter eleven was 1355 p.s.i. and the overall average 1205 p.s.i. The reasons for the three low results are not known; all appeared to be in sound condition visually. Only the lowest value, however, is within the current design range, but again it is comfortably above the earlier maximum stressing figure 230 p.s.i.

3.3. Mouldrite

The test evidence on this appears to be similar to that of Beetle A. Fifteen glider-component specimens have been tested by Slingsby Sailplanes Ltd. They were taken from fuselage frames of Petrel, Cadet and Kite 1 aircraft, and all were 17 or 17½ years old.

One specimen failed at 795 p.s.i. and the remainder at between 1050 and 1865 p.s.i. the average being 1385 p.s.i. Thus all values indicate ample strength margins above design figures.

4. Casein Glues

Ref. 8 gives some data for tests on casein glues. As with the U.F. tests dealt with in 3.1.1. above, the figures relate to mean values for twelve test pieces, but in this case they are for close-fitting joints only. (For work in which strength is important, casein is not suitable as a gap-filling glue.) The percentage strengths were:

Ref.	Storage Conditions	Man'd	Initial Failing Load lb.	% Strength 5 years	10 years
L282	Indoors at 25°C	1944	700	95	85
L593	and 60% R.H.	1946	700	95	85
L645		1947	755	95	85
L507	In box in open	1945	—	95	(2)
L516	field	1945	—	100	(2)
L645		1947	—	(1)	—

Figures in brackets indicate delamination by micro-organism attack after (1) 3 years, (2) 8 years.

These somewhat limited results indicate that, for the particular samples tested, the specification failing load is liable to be just reached in about 10 years if the joints are stored in the indoor conditions quoted, and also illustrate the well-known fact that exposure to damp can render the glue useless. It is interesting to note that, in the case of the fourth and fifth sets of test pieces, the strength at 60% of what proved to be the life was hardly affected.

5. Resorcinal-Formaldehyde Glues

Ref. 8 again gives some data, for both close-fitting and gap joints. The percentage strengths were:

Type	Storage Conditions	Man'd	Initial Failing Load lb	% Strength 5 years	10 years
Close	Indoors at 25°C	1945	820	95	90
Contact	and 60% R.H.	1946	770	95	90
		1947	720	85	80
		1944	780	95	90
	In box in open	1945	820	95	90
	field	1946	720	100	95
		1947	720	95	90
Gap	Indoors at 25°C	1945	600	95	85
		1946	600	95	85
		1947	570	95	95
		1944	650	100*	—
	In box in open	1945	600	85	75
	field	1946	600	85	70
		1947	570	85	80

* 6 specimens, 3 years.

The 1947 close-contact specimens stored indoors and the 1946 gap-joints stored outdoors were just below the specification figure of 600 lb. and 450 lb. respectively at 10 years; all the others remained above specification.

6. Practical Experience of Gliders in U.K.

Results from test specimens form only part of the evidence in considering the airworthiness of wooden structures. On the one hand, the glue in test specimens is rarely subjected to pureshear, and on the other the conditions to which the specimens have been exposed prior to test do not reproduce the variations in temperature, humidity and stress which occurs in service. In real structures, also, the glue may be exposed to some direct stress, though in good design this is avoided as far as possible.

The final test of an adhesive is its behaviour in service. Experience on gliders of casein and U.F. glues differs in several respects. In the U.K., casein runs to around 1000 glider-years, ignoring primaries and the war years themselves, and the earliest machines currently certificated are 28 to 30 years old. U.F. experience totals approximately 4000 glider-years, the oldest machine being aged about 18 years. The two types are therefore discussed separately.

First, however, it is necessary to describe briefly the inspection procedure used for civil gliders in the U.K. at the present time, and this is the same for all gliders irrespective of the type of glue used. Each glider has an annual overhaul for renewal of the Certificate of Airworthiness under either B.G.A. or A.R.B. auspices. Moreover, the B.G.A. now requires a major overhaul ten years after the granting of the initial C. of A. and then at 5-year intervals. Under the latter scheme, which was started in 1960, the inspection preceding the overhaul must be carried out by a B.G.A. Senior Inspector, who must submit a strip report to the B.G.A.

6.1. Urea-Formaldehyde Glues

Three foreign gliders built of some unknown glue which may have been a U.F. and some odd components of Kaurit, are known to have been condemned because of glue deterioration. In all these cases, the poor condition of the glue was very obvious and unmistakable. As far as is known, no British U.F. built glider has had to be scrapped on this account.

Some 32 major overhaul inspections of U.F. machines were made from 1960 to 1962, half being on privately-owned and half on club-owned gliders. With the exception of one each in 1951 and 1952, all were built between 1946 and 1949. In the strip reports, the condition of the glue is described, broadly speaking, by various terms ranging from "satisfactory" or "sound" to "excellent". The latter was applied to a T.21b which had carried out about 35,000 launches at the time of the inspection. At the time of writing, after another 20,000 launches the description still applies. The only qualifications to the above were in respect of local defects. These concerned five Cadets and Tutors, a Kite 2 and five Olympias. Most defects were minor items such as rib biscuits, fuselage gussets etc. One Tutor, of which the glue was described as "fair", had rather more detached biscuits than usual. Two of the Olympias had seat bearer damage, but this was probably due to rough landings. In no case was any deterioration of the primary structure observed.

The rib-biscuit failures, it is now fair to say, were in the majority of cases almost certainly due to poor assembly technique, largely due to the use of unsanded or inadequately-sanded ply. Many Cadets and Tutors of this period were built by a sub-contractor using Beetle glue for minor assemblies such as ribs, and Aerolite for major assemblies. There were also one or two minor glue failures in early Olympias apparently due to inadequate preparation of thin plywood. Most of these defects became apparent early in the life of these gliders and had been remedied at the time of these major inspections. Beetle was also used for some fuselage frame laminations on early Olympias but there is no record of any glue failure of these components.

In general, the results of these major inspections can be regarded as very satisfactory. All primary structure joints appear to be still going strong, and what defects there have been were secondary or testiary structure and probably not the fault of the glue anyway.

6.2. Casein Glues

Experience with casein, as indicated above, covers a longer period though smaller "volume". The number of casein—built gliders condemned because of glue deterioration is not known with any precision, but, U.K. civil experience still being considered, it is likely to be of the order of one hundered. In assessing this figure primaries have been left out of account; many will not have survived long enough for glue deterioration to occur and the remainder will have been superseded as a result of the change to two-seater training.

13 major overhaul inspections of casein-built machines were made in the same period as above, 1960 to 1962, all being on privately-owned aircraft between 19 and 26 years old. The strip reports indicate some defects on wing and fuselage structure on a 24-year old Kite 1 and on wing-ribs on another Kite 1, 26 years old; all these were local and at places subject to ingress of moisture, some affecting wing ribs and fuselage skin.

In most if not all cases of gliders having to be scrapped, the glue had deteriorated due to the effects of moisture and/or micro-organism attack. This, combined with the fact that all surviving casein gliders are privately-owned and likely to have been well looked after, tends to support the general impression that casein can be satisfactory for long periods, but only provided that real care is taken in maintenance.

7. Inspection of Glued Joints

Since the war, there has not been any significant in-flight failure of a glider structure which could be ascribed to glue deterioration or poor initial assembly of glued joints. There have been failures for other reasons (e. g. excessive loads in aerobatics, and exceeding flight limitations) but from the foregoing data the reliability of glued joints can only be regarded as outstandingly good.

Australian experience of powered aircraft has been less fortunate. A number of failures in the air are mentioned in ref. 9. Some of the aircraft concerned were, however, known to have been manufactured to less rigid standards than those applied to gliders.

The same reference says that U.F. glues suffer deterioration due to time as a consequence of "a complex molecular change", but Ref. 6 gives no evidence that the mechanism is of this nature. Such surmises have caused A.R.B. and D.C.A. to believe that glue deterioration, purely as a function of time, cannot be observed by the normal processes of visual and manual inspection. The sub-committee of the Aviation Committee of the Royal Aero Club set up in January 1963 to consider the airworthiness of wooden light aircraft takes the view that "— to a skilled wooden aircraft inspector, there are several indications of co-incidental deterioration which are likely before the glued joint itself deteriorates to the stress level assumed by the designer and to a level likely to prove catastrophic." The B.G.A. supports this opinion. In relation to the Australian experience it is significant as ref. 9 itself points out, that in 1954, when the first in-flight failure (due to a faulty splice) occurred, there were in the N.S.W. region, where the majority of wooden aircraft were based, only 3 out of 830 licensed aircraft maintenance engineers who were fully rated wooden aircraft tradesmen.

Molecular changes may occur, but whether they do or do not is not in itself necessarily important. What is important, we feel, is what can be seen, felt and smelt. The foregoing information implies that initially sound joints tend to remain sound unless subjected to influences which are generally more amenable to inspection than molecular phenomena. Also, an initally poor joint (e. g. one made with unsanded ply) will tend to shew evidence of failure which can be detected by visual inspection. For instance, if rib biscuits can be flicked off with light finger pressure, the glueing was probably unsound in the first place, although the Slingsby Sailplanes Ltd., tests indicated that even in such circumstances the strength of the joint in shear could still be quite high. If rib biscuits cannot be flicked off in this fashion, the joint was probably quite well made, and is unlikely to give trouble in normal service.

One of the authors has seen a ten-year old "Sky" wing on which no rib biscuits could be removed by finger pressure. Using appreciable force to break off a biscuit resulted in wood failure. Equally, he can recall a "Tutor" wing, not of Slingsby manufacture, two years old in 1949, in which numbers of biscuits had just fallen off the ribs, due to the use of unsanded ply. In general, evidence of poor assembly technique is more likely to be present in light assemblies or other components where it may be difficult to ensure uniform clamping in manufacture, and the evidence provided by such assemblies is often a good guide to the integrity of the structure. An experienced inspector, in our opinion can form a very good idea of the condition of glued joints by looking for separation of ply/timber joints, cracks in glue fillets, hollow sounds on tapping skin/spar or skin/rib joints, signs of moisture, and with casein, any odour, and so on. Accident damage also provides valuable information; the nature of local failures is apparent, and poor assembly would tend to permit failures remote from points of local damage.

8. Conclusions

From test data and practical experience described above, taken as a whole, it is concluded that, with satisfactory assembly techniques and storage conditions as should be normally applicable, glued joints on gliders in U.K. operation have not been responsible for any reduction in airworthiness beyond the point for which current inspection requirements and methods are adequate. This applies for casein and Aerolite 300 up to at least 26–28 and 17–18 years respectively. Other U.F. glues, such as Beetle A and Mouldrite, have been reasonably satisfactory within the very limited experience of them; indeed these glues are no longer used for gliders, though some components assembled with them are still in service. For resorcinal formaldehyde glues, aircraft experience is as yet small, but the manufacturers' opinion is that they will prove better than urea-formaldehyde so long as the rather more exacting application techniques and shop conditions are complied with. No case can be seen for setting any definite life for gliders built with any of the glues mentioned, subject to storage being in reasonable conditions and to proper maintenance and inspection being carried out. Particular care is required for casein.

9. Acknowledgments

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