STRESS COMPARISON FOR COMPOSITE GLIDER LIFE-TIME ESTIMATION

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1. INTRODUCTION

The certification procedure for operational gliders requires the structure lifetime (fatigue life) to be set. This can be performed on the basis of:

a) Ground fatigue tests on representative structure components. In practice, the wing is the component having the highest stress level and the main responsibility for flight safety.

b) Experience gained to date includes the operation of composite gliders.

c) Ground fatigue tests are done on the selected structure components or details which are responsible for the whole glider safety. In most cases it is the wing root and main fittings where the problem of distributing the concentrated force into the shell should be substantiated.

d) The ground fatigue tests on one type of glider may be used as a base for comparison with another, if the structure and loading spectrum are sufficiently similar.

The last item (d) is the subject of this paper.

It is obvious that the comparison would be better if the statistics on fatigue test results were more extensive.

2. COMPARISON BASIS

Statistics have been gained in Poland during fatigue testing the following gliders:

a) Tests on the whole wing:
- SZD-48-1 "Jantar Standard 2"
- SZD-51-1 "Junior"

b) Tests on the wing spar root portion with fittings:
- SZD-37 "Jantar"
- SZD-38 A "Jantar 1"
- SZD-42-2 "Jantar 2B"
- SZD-45 A "Ogar"
- SZD-50-3 "Puchacz"
- SZD-55

c) Tests on the fuselage central part steel tube framework with wing root portion:
- SZD-9bis-1E "Bocian"

The results obtained in the above tests have been used as the basis for:
- setting the glider fatigue life,
- extension of the fatigue life for gliders in operation which have completed the flying hours of the previously established life of the structure,
- comparison between the new design and the pattern structure already tested. In this case the similarity of the structures and loading characteristics are important.

3. PATTERN FOR COMPARISON

For the comparison to be valid, the subject structure and the pattern one must meet the following conditions:

a) The same characteristics of the design material (Reference 6).

b) The similar structure concept for the main glider components.

c) The same class of the glider (Standard, Open, Club etc.).

d) The similar loading level depending on aerodynamic and mass characteristics of the glider.

e) Similar way of loading distribution in the stressed structure (internal organization of the structure).

f) The same workshop procedures and environmental conditions during the production pro-

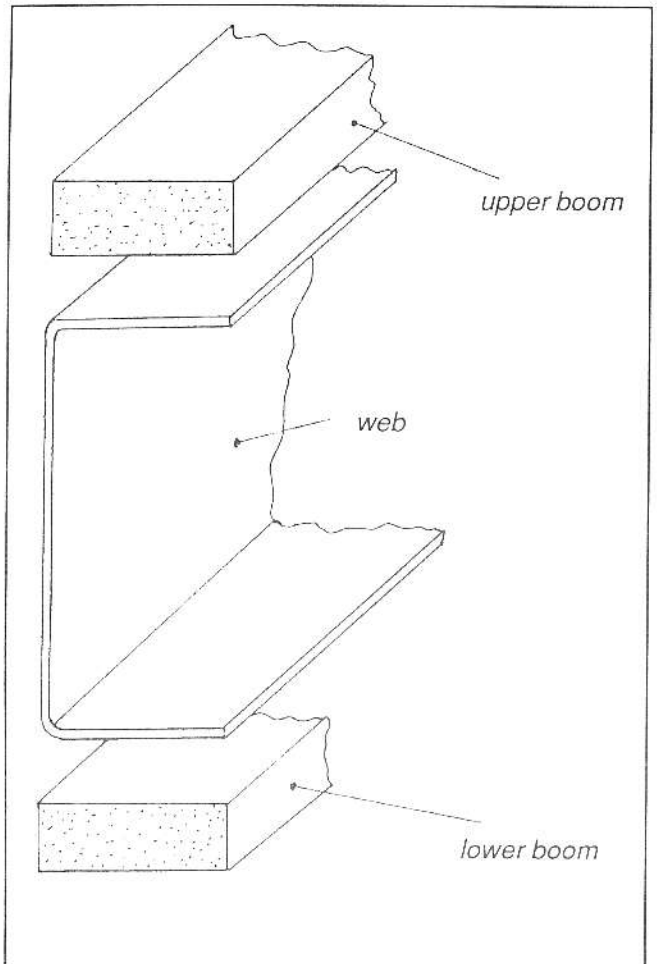

FIGURE 1. Spar Details. Upper and Lower boom.

cess of assemblies and details (the workers' skill included).

g) The same assembling technique used for connecting the main glider components.

h) The same inspection and quality control system.

For the SZD composite gliders produced by "PZL-Bielsko" factory two pattern models have been selected, namely: SZD-48-1 "Jantar Standard 2" and SZD-51-1 "Junior". The reason for the above selection was:

- the SZD-48-1 has a wing with main spar of a box form manufactured as a separate unit and glued in between the upper and lower wing shells during the assembling procedure.
- the SZD-51-1 has the roving spar booms (Figure 1) and the web manufactured separately and joined together during the whole wing assembly operation.

Both pattern wings have been subjected to the loadings prescribed in the form of function of load factor "n" versus number of loading cycles "H".

4. PATTERN FATIGUE TEST PROGRAM

The program consists of particular loading blocks, each one corresponding to the particular operation condition (Reference 1).

The program for the SZD-48-1 consists of the following blocks:

- ground-air-ground,
- gusts in aerotowing,
- gusts on circling in thermals,
- gust on interthermal flight,
- gust during winch-launching,
- rolling on the ground.

All the above blocks are doubled, for water ballast and no ballast configurations.

In case of the SZD-51-1 there is no water ballast provision. However, the above blocks are supplemented with blocks for:

- school flights,
- basic aerobatics (Reference 4),

The fatigue test programs for both of the above gliders have been based on:

- flight measurements (Reference 5),
- theoretical considerations.

In the case of the SZD-48-1 the acceleration in the vicinity of glider C.G. was measured, especially for the on-ground loadings.

For the SZD-51-1, extensive in-flight and on-ground loading measurements were completed using a specially developed technique. The extension gauges were

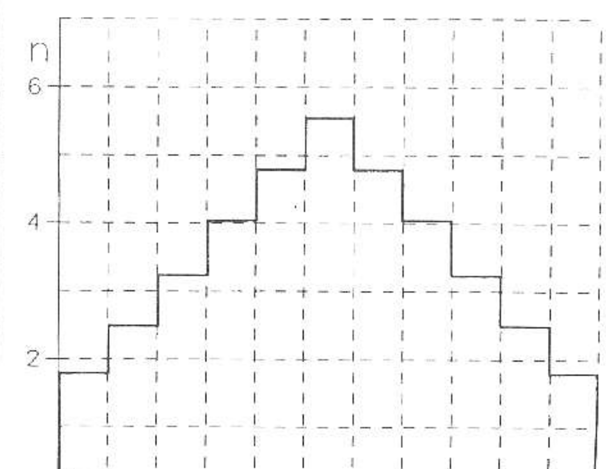

FIGURE 2. Loading spectrum of gusts in interthermal flight. SZD-48-1 "Jantar Standard 2" glider. Full water ballast configuration.

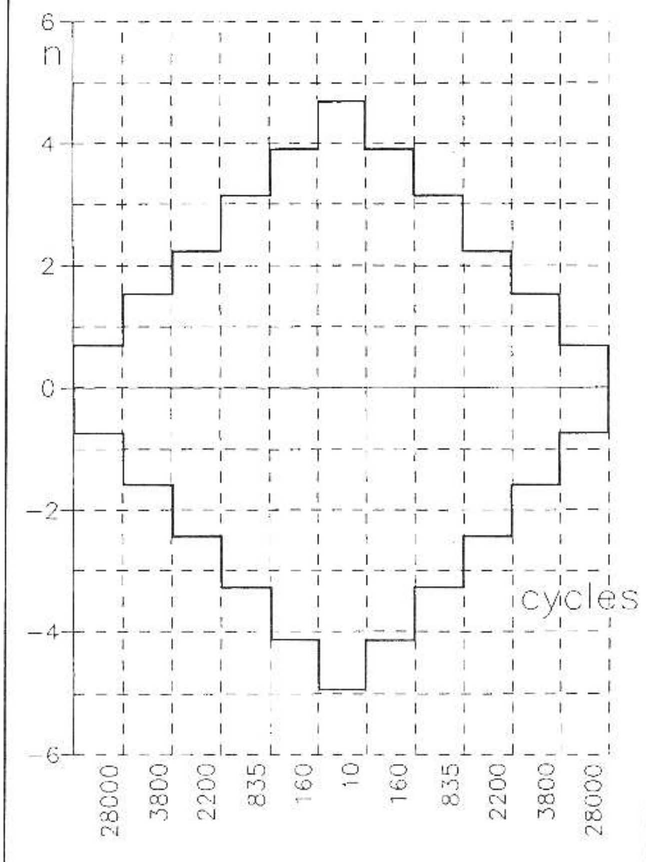

FIGURE 3. Loading spectrum of ground rolling. SZD-48-1 "Jantar Standard 2" glider. Full water ballast configuration.

glued to the wing spar boom at the root rib cross-section and calibrated on the ground when the wing was loaded to defined values of bending moment corresponding to various load factors "n".

The records taken during flight and ground rolling provided data for the loading spectrum. This spectrum, compared with the records at the glider C.G., allowed determination of the wing response as a function of time. In this way the true wing loading spectrum was obtained as a basis for designing the fatigue test program.

The program was prepared for 1000 flying hours. If it is intended to approve, e.g. 3000 flying hours life, it is necessary to repeat the whole program kh = 3 times.

Since the test is carried on one wing only (for economic reasons) the scatter factor must be taken into account (Reference 2). In the absence of more detailed consideration, this factor is commonly accepted as $k_S = 3$.

Hence, to substantiate a life of 3000 flying hours the whole program should be repeated 9 times, and for 6000 flying hours, 18 times.

When all "k" passes of the program are completed the wing must be subjected to a static test (if it did not fail in the fatigue test) in which the 150 percent safety margin must be obtained.

Since the whole program for ballast and ballastless configurations is a complex diagram, it is illustrated here by four blocks only. They are:

- for SZD-48-1
  - a) Gusts in interthermal flight with full water ballast (Figure 2)
  - b) Ground rolling with full water ballast (Figure 3)
- for SZD-51-1
  - a) Gusts in winch launching (Figure 4)
  - b) Basic aerobatics (Figure 5).

5. COMPARED STRESS

The stresses in the wing reach the various levels in different regions, so it is necessary to select the location in which the stress is representative for making the fatigue properties prediction.

Analysis of the stress level in most of the existing composite gliders shows that the critical cross-section is located in the vicinity of the wing root rib, and for bending stresses the spar appears to be the element representative of the whole wing structure. Therefore, the comparison of the stresses in the spar boom (see Figure 1) at the root rib station seems to be the best reference point in estimating the stress level. If this level is lower than in the pattern wing, we can conclude that

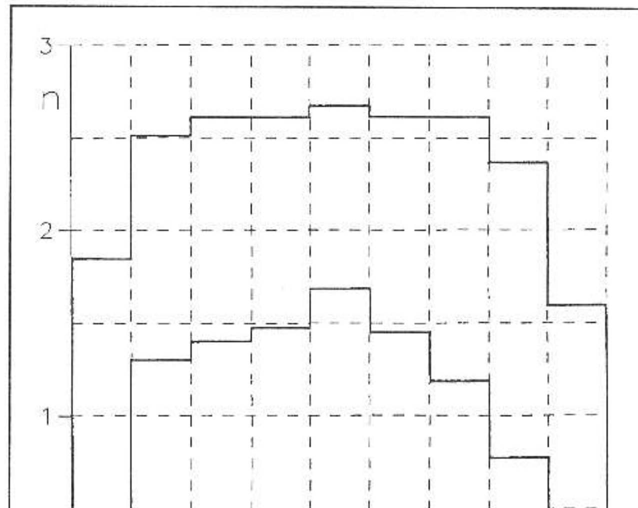

FIGURE 4. Loading spectrum of gusts in winch-launching. SZD-51-1 "Junior" ballastless glider.

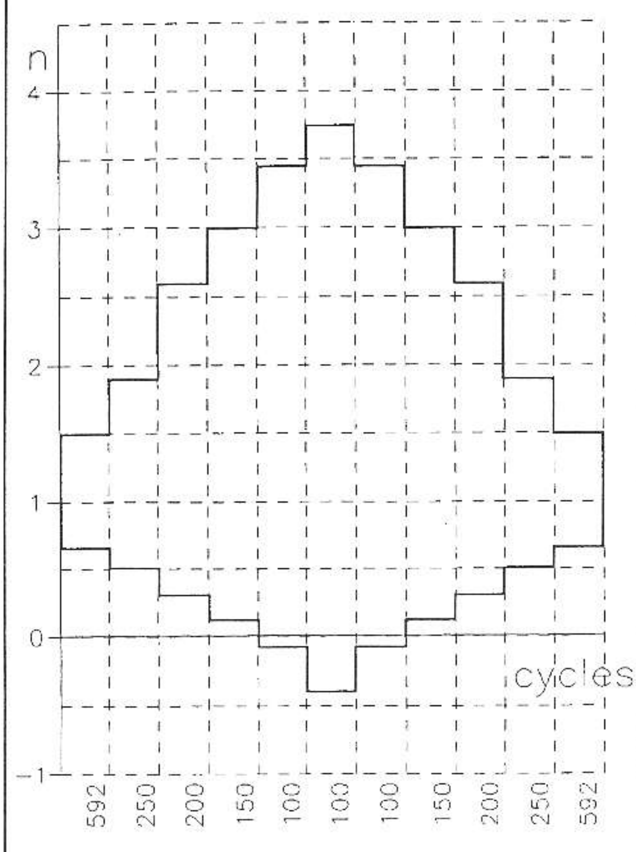

FIGURE 5. Loading spectrum of basic aerobatics. SZD-51-1 "Junior", balastless glider.

the anti-fatigue properties of the analyzed wing should be of at least similar order to that of the pattern wing.

The program for the ground fatigue test is expressed in the form of load spectrum:

n = f(H) where "n" = load factor and "H" = number of loading cycles.

For the comparison purpose this spectrum is transferred into the stress spectrum:

σ = f(H) where "σ" = stress in the reference station of the wing spar boom.

The bending moment at the reference cross-section for the particular load factor value "n" and the wing cross-section geometry determine the stress value. This transformation of n = f(H) function into the σ = f(H) is made for both the pattern and the analyzed gliders.

6. STRESS SPECTRUM

Within each loading block, the loading increases and decreases (see Figures 2,3,4 and 5 as an example) in an ordered way. For the comparison it is necessary to design the stress spectrum in a cumulative form, to obtain the diagram of function:

σ = f(Hc) where "Hc" is the cumulative number of cycles.

An example of such a spectrum is shown on Figure 6 for the SZD-51-1 glider.

7. COMPARISON OF STRESS SPECTRA

To determine the life of the structure the stress spectra comparison should be performed.

On Figure 7 the spectrum for SZD-50-3 "Puchacz" glider has been compared with the pattern one, namely spectrum for SZD-48-1 on which the ground fatigue test was made. The solid line shows the pattern SZD-48-1 spectrum, the dashed one is of the compared SZD-50-3 "Puchacz" glider. In most areas, the SZD-50-3 spectrum is covered by the pattern one; the area where the SZD-50-3 spectrum exceeds the pattern one is shaded. This, however, concerns only the low stress level of compression of the lower spar boom (negative portion of the spectrum). It could be hardly supposed that such a low stress could have any significant influence on the fatigue behaviour of the structure.

On the basis of the above comparison the satisfactory life time substantiation for SZD-50-8 structure can be concluded.

In respect of the material characteristics, the compression of spar boom appears to be the critical one. Since the positive (upwards) wing bending is for most glider types greater than the negative one, the critical item is compression in the upper spar boom, therefore in most cases it would be sufficient to compare this compression.

Such a comparison of the upper spar boom compressive stress of SZD-55-1 sailplane with the pattern com-

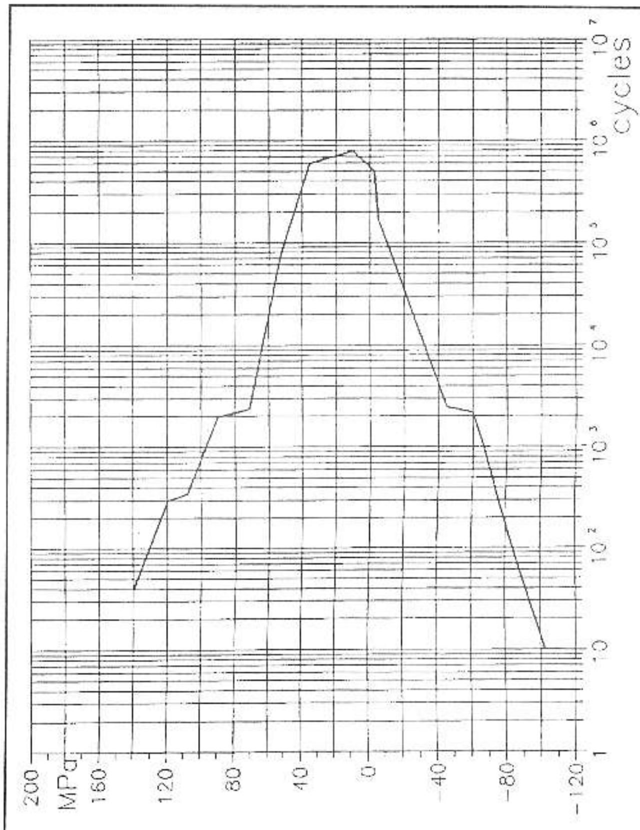

FIGURE 6. Cumulative stress spectrum of SZD-55-1 "Junior" glider.

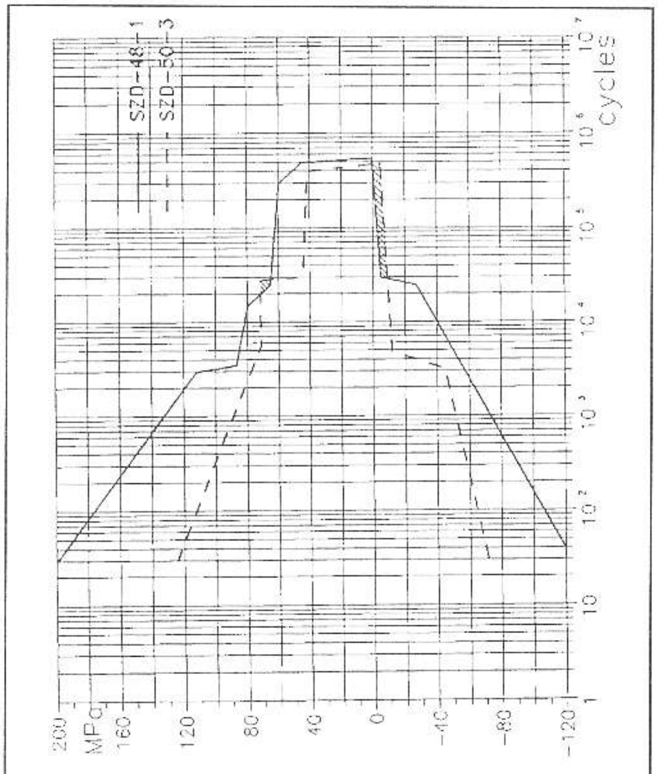

FIGURE 7. Comparison of cululative stress spectra of SZD-48-1 "Jantar Standard 2" and SZD-50-3 "Puchacz" gliders.

pression of SZD-51-1 "Junior" glider is shown on (Figure 8). The uncovered region of SZD-55-1 spectrum (shaded area) again appears for the low stress level, so all the remarks discussed above are valid for this case also. However, because the main spar fitting of SZD-55-1 sailplane is of different design from that of the SZD-51-1 "Junior" it was necessary to perform an additional fatigue test for the wing fitting part. Consideration of both the comparison of stresses and the test of the main fittings of the SZD-55-1 wing permitted determination of the fatigue properties of the structure and hence of the life.

8. CONCLUSIONS

The ground fatigue tests of gliders for the substantiation of the fatigue lives are very expensive ones. So advantage should be taken of every method which is cheaper but can be substituted for the fatigue test. Even where these methods are not completely acceptable to the Authorities as means of substantiation, they can be used as an auxiliary tool to gain a general opinion on the structure fatigue properties.

The method described is based on the compression stress level comparison through the whole cumulative stress spectrum in the selected critical structure component.

Experience to date indicates the wing to be the critical component and the critical station to be in the vicinity of the root rib. The stress in the upper spar boom seems to be the most suitable location of the representative stress for predicting the life of the structure.

The important thing is how closely the compared gliders meet the requirement of design similarity, as defined in chapter 3.

The present paper does not pretend to prescribe a complete method to be introduced as standard practice at once; the proposition needs to be discussed and criticized. It can, however, be classified as advisory material in establishing or extending the glider life.

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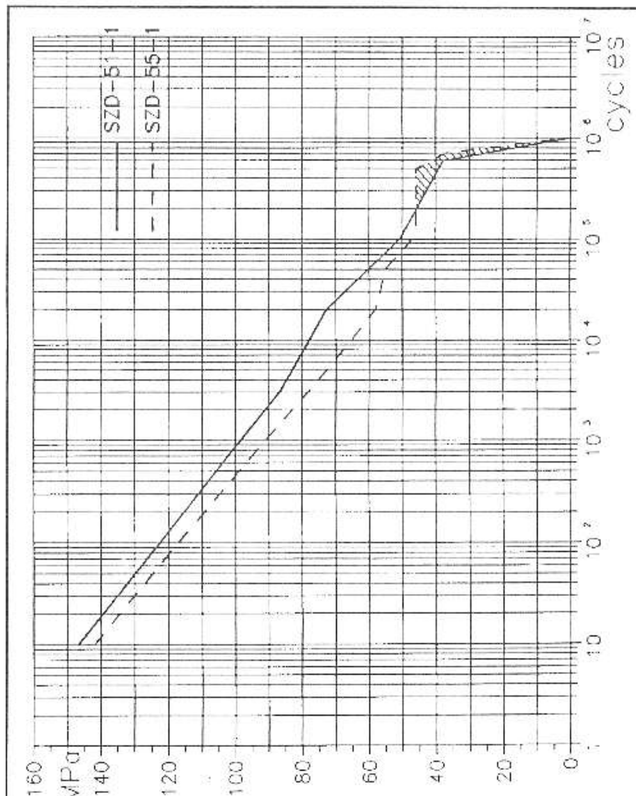

FIGURE 8. Comparison of cumulative stress spectra in the upper spar longeron (cap) of SZD-51-1 "Junior" and SZD-55-1 gliders.