The Wing Loading Spectrum of a Glider in Aerobatic Maneuvers Measured on a Training Two-Seater SZD-9bis "Bocian"

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INTRODUCTION

To define the fatigue-safe life of a glider, the analysis of various flight conditions is necessary. The wing appears to be the critical design element for appreciation of the safe-life of the whole aircraft structure, since the stress level and loading variation make this component a representative one. The maneuvering loads in aerobatics are of concern in the case of a two-seater designed for primary and advanced training in both solo flight and with an instructor.

To design the fatigue test program for a wing, the flight test data on the load level and frequency are required. Such data have been gathered during flight test of a "Bocian" two-seater completed in 1981 at Bielsko-Biala, Poland.

GLIDER UNDER TEST

The tests have been carried out on a two-seat SZD-9bis "Bocian."

Wing geometry:

Span	17.805 m
Area	20.000 m^2
Mean Standard Chord	1.120 m
Aspect ratio	16.200

Wing sections: linear transition NACA 43018 at root into NACA 43012 A at tip.
Slope of lift characteristics dC_L/di: 5.150 /rad

Masses:

Empty glider	360.0 kg
Wing structure	175.5 kg
Maximum all-up	540.0 kg
Wing loading	27 kg/m^2
C.g. location (% of MAC)	21.7 to 38.8

Basic airspeeds:

Stalling	58.4 km/h
Maneuvering	150.0 km/h
Never exceed	180.0 km/h

Load factors: +6 and -3 (this glider was designed in 1951 when the conservative Polish Requirements were obligatory).

"Bocian" is of wood construction with cantilever wings and normal tailplane arrangement. The extended air brakes on the wing operate up to 180 km/h airspeed. The fuselage with fixed wheel contains a comfortable crew cockpit for pilots and instructors of various body mass and dimensions.

TEST MEASUREMENTS

To measure the load factors, the glider was equipped with SFIM apparatus which continuously registered the changes of acceleration on an osciloscopic tape at the glider c.g. On the same tape, the time base was marked.

The glider was flown by a group of pilots having both high and low experience in aerobatics. The measured aerobatics consisted of several maneuvers including: spinning, looping, stall-turn, spiral, quick half-roll-half-loop.

The wing loading varied, within the allowed limits as listed in the Flight manual, due to the combination of the body masses of pilot and instructor.

RESULTS

The values of maximum and average positive load factors are listed in Table 1.

Manoeuvre	Maximum load factor	Average load factor
Spinning	3.2	2.5
Looping	4.6	4.0
Stall turn	4.6	3.5
Spiral	3.0	2.5
Turn with climbing	3.6	3.0
Quick half-roll-half-loop	3.6	2.5

Table 1 Load factors in particular aerobatic maneuvers

The loading spectra measured for low and high experience pilots are different; this has been taken into account in analysing the results.

The ratio of maximum positive to negative load factor is: 5.3/2.65 = 2, as defined by the requirements applicable to "U" - category (Reference 2). This ratio in test appeared as 4 for low experience and 3.5 for high experience pilots.

The loadings oscillate with respect to the basic level of n = 1. Using the designation "n_i" for an arbitrary loading level, the incremental load factor is:

$$\Delta n = n_i - 1$$

The ratio of positive to negative incremental load factor was found to be a function of positive factor value (Figure 1).

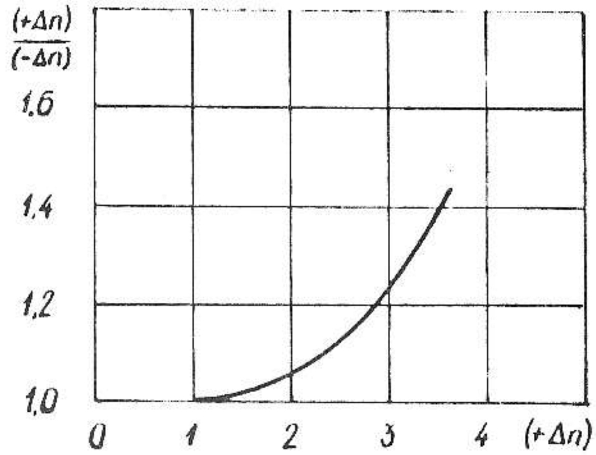

Fig. 1 Ratio of positive to negative load factor

The measured load factors show the domination of positive values, which is commonly shown for pilots performing the basic aerobatics.

The total time used for the test flights consisted of a portion for pure aerobatic maneuvers (active time "t_a") and a portion for aerotowing, level flight between sets of maneuvers, eventual climb in thermals, straight glide from the altitude (being the lower level allowed for aerobatics), and approach and landing (passive time "t_p"). The average ratio of active to toal time was found to be:

$$e = t_a/(t_a + t_p) = 0.11$$

The continuous load spectrum registered on the tape has been transformed into a graduated one at intervals of 0.5 g. In this way the "load levels" were obtained. All the loading peaks adjacent to a particular level of $\pm$ 0.25 g have been counted as attributed to this particular level.

The load peaks have been summarized for positive and negative values separately. It has been found that the positive load factor changes were more frequent than the negative ones. All the peaks were lower than the values defined by the n-V diagram, as confirmed by other tests (Reference 5).

The positive load factor changes are more frequent than the negative. Their ratio was:

K_{le} = 1.94 for low experience pilots, and
K_{he} = 2.32 for high experience pilots.

The above figures confirm the fact that basic aerobatics performed in a skilled manner mainly produce positive accelerations. The unskilled pilots make the control mistakes which result in higher amounts of negative load change.

To put the data in a form convenient for designing the load spectrum, the total number of load peaks were counted with respect to time:

- low experience pilots b_{le} = 52 changes per hour
- high expereince pilots b_{he} = 43 changes per hour.

The greater amount of loading peaks per hour for low experience pilots depends on control mistakes or faults such as sudden and ragged stick or pedal action.

Both b_{le} and b_{he} values depend on the total time of flight. Taking as a base the time for pure aerobatics "t_a" these values should be divided by e = 0.11.

LOAD FACTORS

The maximum registered positive incremental load factor was 3.0 and 2.5 for low and high experience pilots respectively. All the other load factors changed within the limits: $\Delta n_{max} > \Delta n > o$ and peaked about the basic level n = 1.0 taking the positive and appropriate negative values (Figure 1).

For the purpose of designing the load spectrum it is convenient to use the relative incremental load factor:

$$m_i = \Delta n_i / \Delta n_{max}$$

where:

Δn_i - incremental load factor for a particular load level

Δn_{max} - maximum positive incremental load factor.

FREQUENCIES

The amount of load change passing the particular load level has been counted. The sum of these changes produced the cummulative value. The cummulative value of changes for a particular load level "F_i" divided by the total amount of load changes "F_{tot}" gives the relative frequency "h_i" attributed to the load level "m_i":

$$h_i = F_i / F_{tot}$$

The relation $h_i = f(m_i)$ describes the relative frequency versus the relative incremental load factor. This relation for low and high experience pilots is shown on Figure 2 and Figure 3 respectively.

The time used for training in aerobatics as a fraction of total glider life was defined on the base of the training program (Reference 6) and glider log-books (Reference 7):

$$T_{aerob.} = 0.2\ T_{gl}$$

where:

$T_{aerob.}$ - time used for training in aerobatics

T_{gl} - total glider life for which the fatigue-safe operation is to be proved.

The amount of total load changes is:

$$(F_{tot})_{aerob} = j_1 \cdot j_2 \cdot b \cdot T_{aerob}$$

where:

j_1 = 0.5 is the factor taking into account the ordered loading sequence when compared with the stochastic one in operation (Reference 3)

j_2 = 2 ratio wing load frequency to load frequency at glider c.g.

b = b_{le} or b_{he} changes amount per hour for low and high experience pilots respectively.

The cummulative amount of load changes

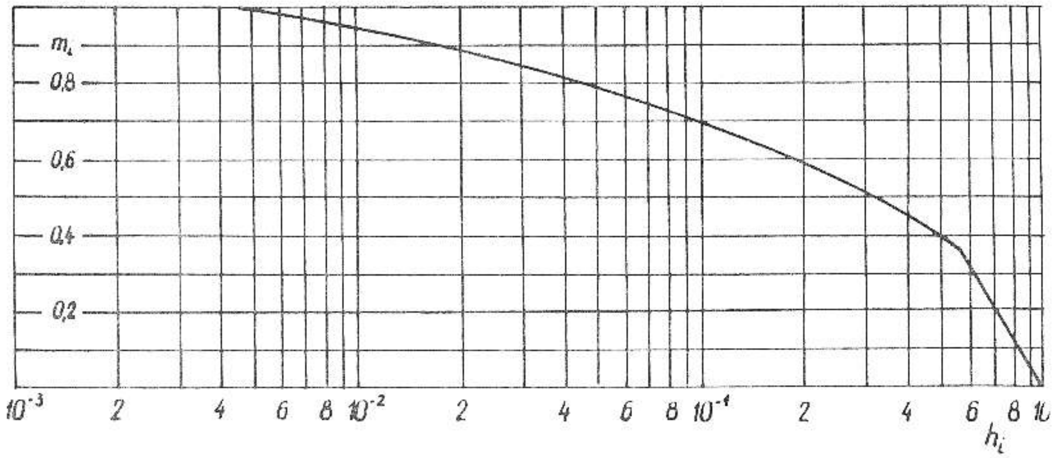

Fig. 2
Variation of m_i with h_i for low experience pilots

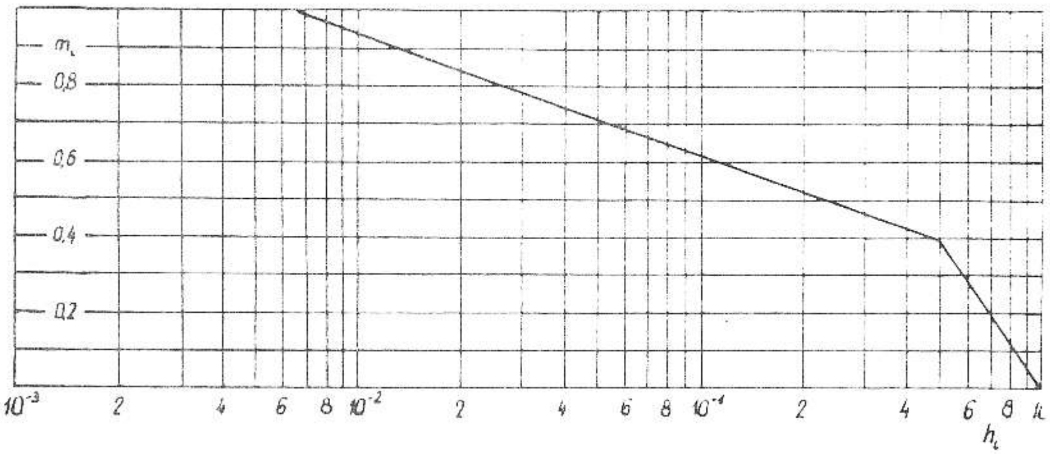

Fig. 3
Variation of m_i with h_i for high experience pilots

for the particular incremental load factor level "m_i" is:

$$F_i = h_i \, (F_{tot})_{aerob}$$

CONCLUSIONS

The measurements of loading spectrum in aerobatics for a two-seater "Bocian" produced some general data for designing the fatigue test program. The test was completed for the glider flown by low and high experience pilots. The purpose was to obtain data useful for training sailplane spectrum (low experience pilots) as well as for high performance sailplane (high experience pilots). Although the aerodynamic characteristics of the "Bocian" and modern high performance gliders are different, the data measured can be extended on both classes of gliders.

The corresponding data on load spectra measured on a single-seater would be very valuable in designing the fatigue test program, but so far no such measurements have been reported.

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