Wing Loading Spectrum of Glider in Aerobatics measured on Training Two-Seater SZD-9bis "Bocian"

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1. 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 set for appreciation of the safe-life of the whole aircraft structure since the stress level and loading variety make this component a representative one. The manoeuvring loads in aerobatics is rather a frequent case for two-seater designed for primary and advanced training in solo flight as well as 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 the flight tests of "Bocian" two-seater completed in 1981 at Bielsko-Biała, Poland.

2. Glider under Test

The test have been carried on two-seater SZD-9bis "Bocian".

Wing geometry:

Span	17.805 m
Area	20.000 m²
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 1/rad

Masses:

Empty glider	360.0 kg
Wing structure	175.5 kg
Maximum all-up	540.0 kg
Wing loading	27 kg/m²
C.g. location (% of MSC)	21.7 to 38.8

Basic airspeeds:

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

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

"Bocian" is the wooden plane with cantilever wings and normal tailplane arrangement. The extended air brake on wing is operated up to 180 km/h airspeed. The fuselage with fixed wheel comprises a comfortable crew cockpit for pilots and instructors of various body mass and dimensions.

3. Test Measurements

To measure the load factors the glider has been equipped with SFIM apparatus which registered continuously the changes of acceleration on an oscyloscopic tape at glider c.g. On the same tape the time base has been marked. The registration was switched only during the aerobatics.

The glider was flown by a group of pilots having the high and low experience in aerobatics. The registered aerobatics contained a couple of manoeuvres including:

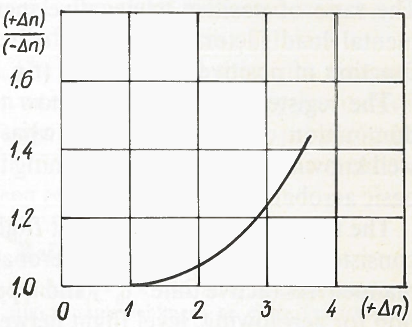

Fig. 1 Ratio of positive to negative incremental load factor as function of positive incremental load factor.

- spinning, looping, stall-turn, spiral, quick half-roll-half-loop.

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

4. Results

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

The loading spectra measured for low and high experienced pilots are different, what has been taken into account in analysis of 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 (Ref: 2). This ratio in test appeared as 4 for low-experienced and 3.5 for high-experienced pilots.

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

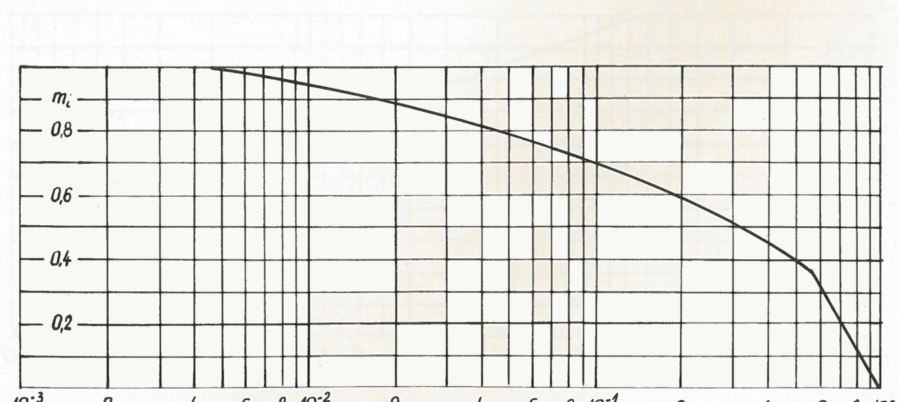

Fig. 2 Relative incremental load factor m_i versus relative frequency h_i for low-experienced pilots.

$\Delta n = n_i - 1$

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

The registered load factors show the domination of positive values, what is well known for the pilots performing the basic aerobatics.

The total time used for the test flights consisted of a portion for pure aerobatic manoeuvres (active time "t_a") and a portion for aerotowing, level flight between couples of manoeuvres, eventual climbing in thermals, stright glide from the altitude being the lower level allowed for aerobatics, approach and landing (passive time "t_p"). The average ratio of active to total 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 the graduated one by intervals of 0.5 g. In such a way the "load levels" have been obtained. All the loading peaks neighbour to a particular level by ±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 n-V diagram, as confirmed by other tests (Ref: 5).

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

K_{le} = 1.94 for low-experienced pilots, and

K_{he} = 2.32 for high-experienced pilots.

The above figures confirm the fact that the basic aerobatics performed on a skilled manner produce mainly the positive accelerations. The unskilled pilots make the controlling mistakes which result the higher amount of negative load changes.

To obtain the data convenient for designing the load spectrum the total amount of load peaks has been counted in respect to time and for:

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

The greater amount of loading peaks per hour for low-experienced pilots depends on controlling mistakes or faults as an effect of sudden and ragged stick or pedal action.

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

5. Load Factors

The maximum registered positive incremental load factor was 3.0 and 2.5 for low and high experienced pilots respectively. All the other load factors changed within the limits:

$\Delta n_{max} \geqslant \Delta n \geqslant \varnothing$ and pulsed about the basic level n = 1.0 taking the positive and appropriate negative values (fig. 1).

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

Zusammenfassung

Um die «sichere Ermüdungsfestigkeit» und die damit verbundene Lebensdauer eines Segelflugzeuges zu bestimmen, ist eine Analyse der diversen Phasen unterschiedlicher Flugbedingungen notwendig. Die Flügel sind dabei das kritischste Entwurfsteil der gesamten Flugzeugstruktur, bedingt durch die Grösse der Belastung und den Wechsel der Last. Insbesondere die Manöverbelastung beim Kunstflug ist bei Doppelsitzern ein Musterfall, wenn diese für Anfänger- und Fortgeschrittenenschulung sowohl einsitzig als auch doppelsitzig mit Lehrer ausgelegt werden.

Um das Testprogramm für die Ermüdungsfestigkeit eines Flügels aufzustellen, sind Belastungsniveaus und -frequenzen erforderlich. Solche Datensätze wurden im Rahmen der Flugerprobung des Doppelsitzers «Bocian» in Bielsko-Biała, Polen, gewonnen und 1981 zusammengestellt.

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

where:

Δn_i – incremental load factor for a particular load level

Δn_{max} – maximum positive incremental load factor.

6. Frequencies

The amount of load changes passing the particular load level has been counted. The sum of changes produced the cumulative value. The cumulative value of changes amount for a particular load level "F_i" divided by the total amount of load changes "F_{tot}" give 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 experienced pilots is shown on fig. 2 and fig. 3 respectively.

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

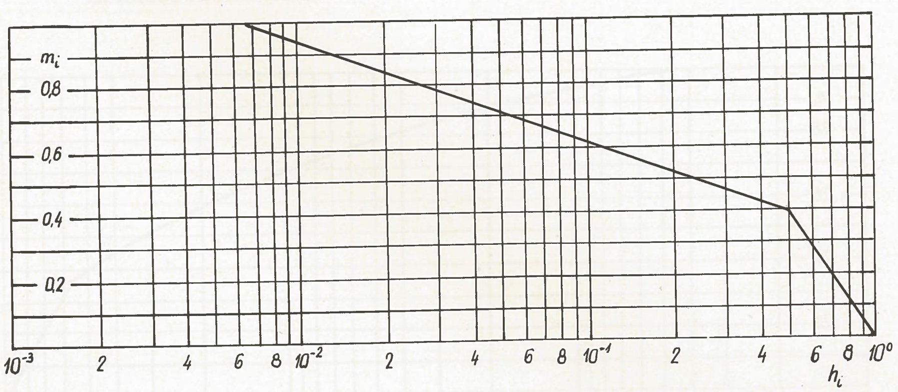

Fig. 3 Relative incremental load factor m_i versus relative frequency h_i for high-experienced pilots.

$T_{aerob.} = 0{,}2\, T_{gl}$

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 (Ref: 3)

$j_2 = 2$ ratio of wing load frequency to load frequency in glider c.g.

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

The cumulative amount of load changes for the particular incremental load factor level "m_i" is:

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

Table 1 Load factors in particular aerobatic manoeuvres

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

7. Conclusions

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

The data on load spectrum measured on one-seater would be very profitable in designing the fatigue test program, but till to-day no such a measurement has been reported.

8. References:

1. *Franzmayer F.K.*: Statische und dynamische Festigkeituntersuchungen an einer Tragfläche des Segelflugzeuges «Cirrus», Deutscher Aerokurier 1969, No 10.
2. Joint Airworthiness Requirements JAR-22.
3. *Kaul H.W.*: Die erforderliche Zeit- und Dauerfestigkeit von Flugzeugtragwerken, Jahrbuch der deutschen Luftfahrtforschung, 1928, pages 1274–1288.
4. *Kensche K.*: Betriebsbelastungsversuch an einem Segelflugzeugflügel in CFK-Bauweise, XVII. OSTIV-Congress, Paderborn 1981.
5. *Stafiej W.*: Flight measured load factors, «Aero-Revue», Zürich, 1973, No's 9 and 10.
6. Training Programm for Glider Pilots, Aeroclub of Poland.
7. Set of log-books and flight scheudules in local aeroclub at Bielsko-Biała, 1980.