Influence of the composite modification of the wooden wing skin of the glider on deflection lines and resonance vibrations

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Abstract: The original wing of the wooden training-glider SZD-9 "BOCIAN", of the Polish production, was modificated by using the additional carbon composite layer. The influence of the addition of a new carbon layer on the mechanical properties of the wing was investigated. Both objects were subjected to static loads, with measuring deflection lines and deformations of wing skin, and to dynamic loads. In dynamic investigations the vibration responses for broad-band excitations were determined as well as the frequencies of the resonance vibrations were tested. The effect of adding a carbon layer is strong damping of the dominant resonant frequency and reduction of the overall vibration level. This effectively makes it difficult to stimulate the construction for vibrations and therefore positively affects the safety of the wing.

Keywords: glider, hybrid composites, deflection lines, vibration, resonance frequencies, product lifecycle management (PLM), reduce, reuse, recycle (3R).

Wpływ kompozytowej modyfikacji drewnianego poszycia skrzydła szybowca na linie ugięcia i drgania rezonansowe

Streszczenie: Oryginalne skrzydło drewnianego szybowca szkoleniowego SZD-9 „BOCIAN" polskiej produkcji zmodyfikowano za pomocą dodatkowej warstwy kompozytu węglowego. Zbadano wpływ nowej warstwy na właściwości mechaniczne skrzydła. Skrzydła oryginalne i zmodyfikowane poddano obciążeniom statycznym z pomiarem linii ugięcia i odkształcenia poszycia oraz obciążeniom dynamicznym. W badaniach dynamicznych określano odpowiedź drganiową na wymuszenie szerokopasmowe i wyznaczano częstotliwości drgań rezonansowych. Efektem nałożenia dodatkowej warstwy węglowej było silne stłumienie dominującej częstotliwości rezonansowej oraz obniżenie ogólnego poziomu drgań, co skutecznie utrudniło pobudzanie konstrukcji do drgań, a w konsekwencji zwiększyło bezpieczeństwo użytkowania skrzydła.

Słowa kluczowe: szybowiec, kompozyt hybrydowy, linia ugięcia, drgania, częstotliwości rezonansowe, zarządzanie cyklem życia produktu i technologii (PLM), ograniczenie, ponowne użycie, recykling (3R).

Modern aircrafts and gliders are produced of polymer composites reinforced with carbon, kevlar or glass fibers. Less and less often they are produced by means of the "classic" technologies of metal and wood. However, units produced of metal alloys and modified wood are still operating. These constructions subjected to natural wearing and occasional defects require several repairs. Since the majority of enterprises is prepared to the laminating technology, covering the defected elements by composite layers becomes presently the natural repair technique [1]. In order to be sure that they can be safely used the in-depth investigations of strength properties, as well as the determination of the joining method of new coatings with the existing structure, are needed [2]. These investigations should be followed by tests of mechanical properties of the modified element. A very good example of the possible modification is the wing of the wooden training-glider SZD-9 "BOCIAN", of the Polish production, widely described by the authors in the monograph [3]. Investigations contained static load tests with measuring the deflection line and the analysis of the vibration response on broad-band excitations, in order to determine the resonance frequencies.

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EXPERIMENTAL PART

Materials

Glider SZD-9 "BOCIAN" is the two-seat training-feat glider, first time used in 1952. Its wingspan is 18 m, which provides approximately 20 m^2 of the carrying surface. The wing used for tests was complete, with all mechanisms, apart from ailerons. The wing length was equal to 8.5 m. The main material used in building the wing was wood. This concerns the inner structure of the wing (girder, frames) as well as the wing skin, which – in addition – was covered by the lacquer layer. Some fragments of wing skin were also made of lacquered linens.

Methods of testing

Tests of the deflection line

Deflection lines of the glider wing with the original skin and with the skin reinforced by a single layer of carbon fabric in the epoxy resin matrix were compared.

The wing was mounted on the stand in the reversed position (bottom side up), due to which the applied load was causing wing bending in the direction being in agreement with the typical operation of this element during a flight (Fig. 1).

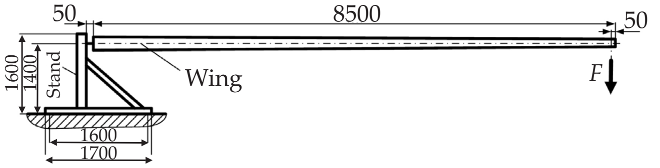

Fig. 1. Schematic diagram of the research stand

The deflection value of the wing was determined by measuring vertical displacements of the selected points of the wing skin. These points were situated on two, previously determined lines: along the front girder (FG) and along the back girder (BG), in other words, stiffenings particularly significant on account of the safe operation of the wing. The deflection of the wing, identical to the deflection of the front girder, directly affects the alteration in glider's aerodynamic efficiency in flight. Measuring points were determined every 500 mm in places where the girder is conjoined with the ribs, on each line. The scheme of measuring points arrangement is presented in Fig. 2.

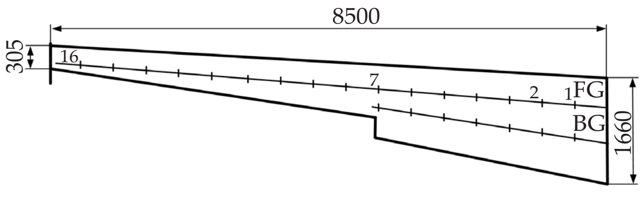

Fig. 2. Schematic diagram of arrangement of measuring points of the glider wing deflection

During the whole test the loading force values were recorded. 3 cycles of the wing loading were performed for each wing skin type. Measurements of the deflection lines were carried out at loads from 0 kN to app. 0.8 kN.

Determination of resonance frequencies

Resonance frequencies [4] were determined on the basis of the vibration accelerations analysis in various points of the wing skin. The measuring path was solely constructed of the elements of the Brüel & Kjaer Company.

Before investigations the geometry of the tested object was reproduced in the Pulse system, the measur-

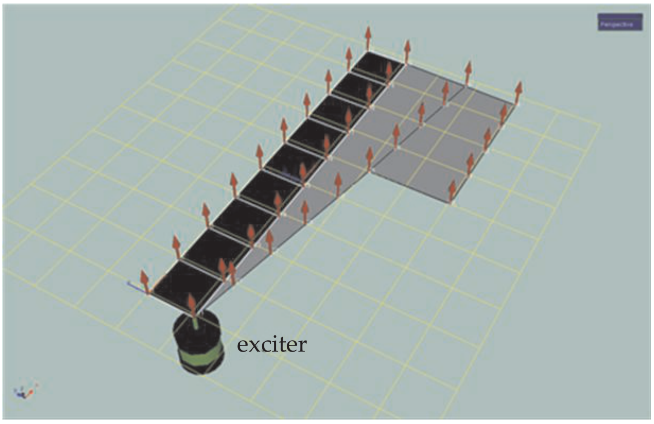

Fig. 3. Schematic diagram of distribution of measuring points (the exciter is the reference point) [3]

Fig. 4. Wing end with the exciter

ing points network was deposited and accelerometers and converters were assigned to these points (Fig. 3). The single-input multiple-output (SIMO) technique, in which there is only one input point, called the reference point (point of excitation by the modal shaker with force transducer) and several output points, *i.e.*, measuring points (where sensors of vibration accelerations were mounted), was applied in the investigations. Places of kinematic pairs, it means places of joining the main and supporting girder with ribs, were selected as places for mounting the sensors of vibrations accelerations, in order not to measure the vibration response of the wing skin only. The view of the wing end with the vibrations exciter is presented in Fig. 4. The wing was excited for vibrations by broad-band noises within the frequency range 1–3200 Hz.

In order to determine the frequency of resonance vibrations the frequency response function (*FRF*) was determined [5, 6].

In a general case the frequency (spectral) response function is defined as:

$$H(f_i) = \frac{B(f_i)}{A(f_i)} = \frac{\text{output signal}}{\text{input signal}} \tag{1}$$

In case of the system excited by the impulse force (*e.g.*, by modal hammer) or by broad-band impulse (*e.g.*, by vibrations exciter) of a known value, in which a noise can occur at the output, the H_1 function is applied [7]:

$$H_1(f) = \frac{B(f)}{A(f)} = \frac{G_{AB}(f)}{G_{AA}(f)} \tag{2}$$

where: $G_{AB}(f)$ – mutual power spectral density of the input and output signal, $G_{AA}(f)$ – power spectral density of the input signal.

This function is very suitable for determining the frequency of resonance vibrations of systems, in which the excitation power and the response for this excitation is known in every point. When it is possible to determine the system response in various points for the excitation caused by the known value power, it is possible to create the so-called stabilizing diagram, determining the response of the object as the excitation function. On its basis it is possible to single out the dominating frequencies, being natural frequencies of the object.

RESULTS AND DISCUSSION

The deflection line

At first the wing with the original wing skin was tested and then the wing with the additional layer of carbon fabric saturated with epoxy resin. Diagram (Fig. 5) presents the deflection lines along the main girder (FG line).

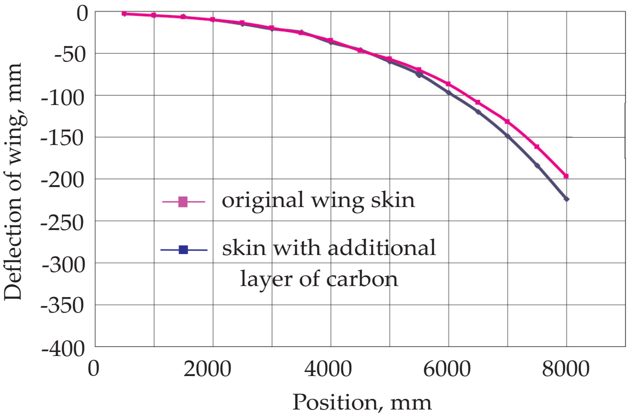

Fig. 5. Wing deflection line for two types of skin at the loading force of 0.5 kN

The obtained results confirmed that the application of the modified (hybrid) wing reinforcement causes essential changes in wing deformations (deflection line). The wing with an additional skin layer is more rigid than before. The significant decrease of the wing deflection at the same loading, on the average of 6 % on the whole length, was noticed. The decrease of the wing deflection means smaller aerodynamic losses, being the result of smaller wing deformations during the flight. It should be noticed, that the increase of the glider weight, by using carbon fibers, is insignificant and in this case equals only ~ 1.5 %.

Resonance frequencies

The performed analyses of the calculated spectral response H_1 function indicate that it is possible to limit the analysis range to 900 Hz, since at higher frequencies the signal has so small energy (amplitude) that it will not influence the structure safety (Fig. 6).

It can be noticed, in the band up to 400 Hz presented in Figs. 7 and 8, that the application of the additional composite layer causes improvements of damping properties of the wing [8]. Not only the amplitudes level decreased in the whole band but also frequency of 284 Hz, dominating in the wing with the original skin, was damped.

Based on the spectral response H_1 functions – calculated for all measuring points – frequencies of resonance vibrations were determined and stabilizing diagrams created. Preliminarily the band within the range of up to 900 Hz was singled out but, due to the quantity of frequencies, analyses were performed within the range of up to 100 Hz. The developed stabilizing diagrams are presented in Figs. 9 and 10. It is worth to notice, that the application of the additional composite wing skin layer decreased by half the number of resonance vibrations frequencies singled out in the modal analysis, by means of algorithms. This means that the hybrid composite structure is more difficult to be excited to vibrations dangerous for the structure.

The wing responses to the vibration excitation caused by some selected frequencies are shown in Figs. 11 and 12.

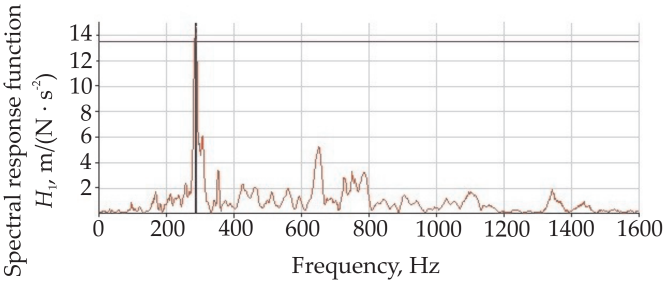

Fig. 6. Spectral response H_1 function for the selected point of the wing with the original skin (wooden wing) within the range of up to 1600 Hz [3]

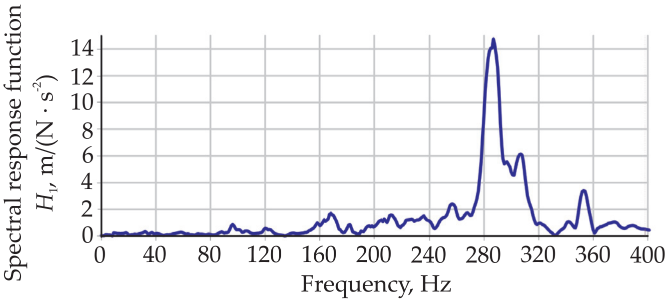

Fig. 7. Spectral response H_1 function for the selected point of the wing with the original skin (wooden wing) within the range of up to 400 Hz

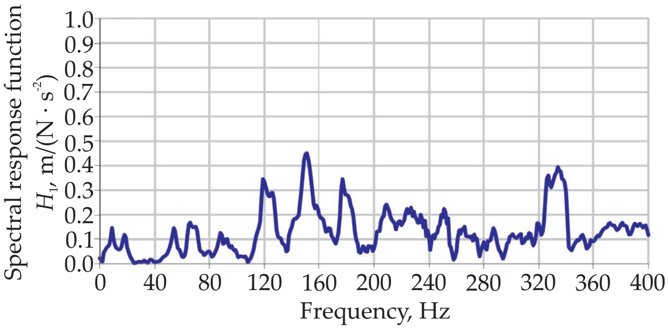

Fig. 8. Spectral response H_1 function for the selected point of the wing with the additional composite layer within the range of up to 400 Hz

The wing skin defect near point 32 (Fig. 12), noticed earlier at the visual verification [9], is very clearly seen in case of the laminated wing at the frequency of 19 Hz.

It should be emphasized that although the first two resonance frequencies remained – in practice – without changes (which is obvious since the composite is elastic), the damping of the dominating frequency threatening the safe usage of the wing occurred.

CONCLUSIONS

It should be emphasized that the investigations of the wing were performed in the moment when the glider was out of service.

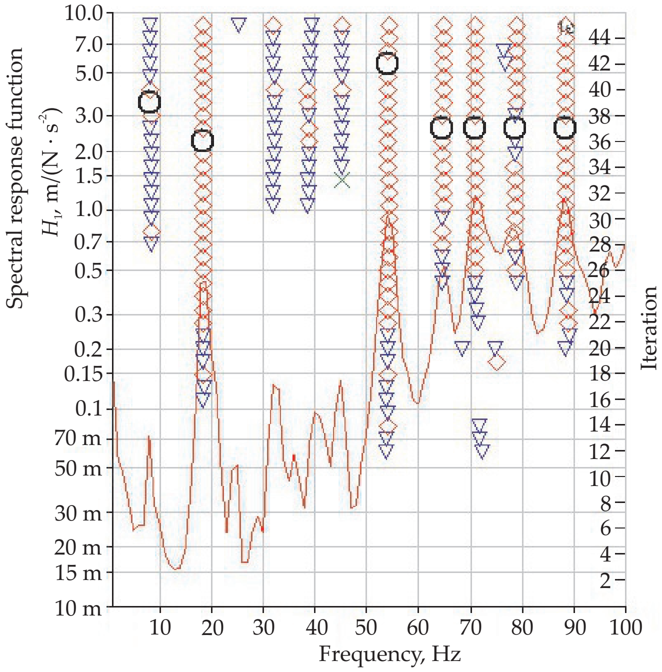

Fig. 9. Stabilizing diagram for the wooden wing [3]

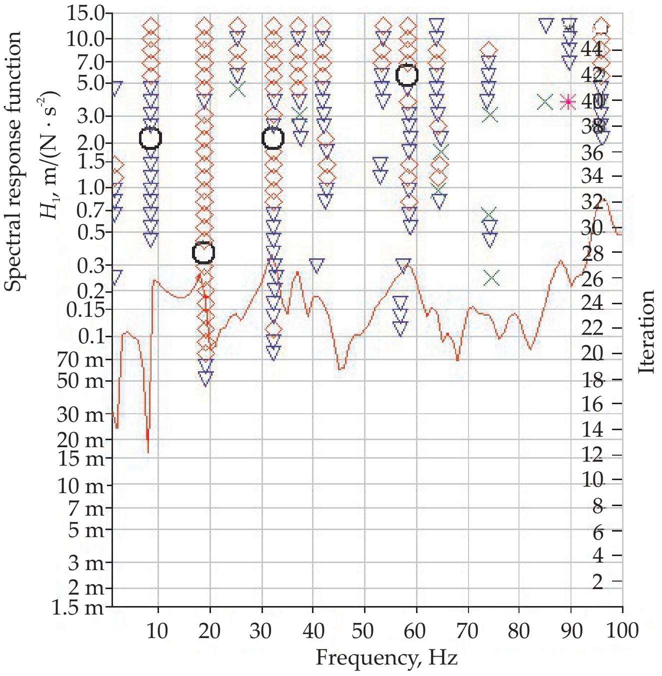

Fig. 10. Stabilizing diagram for the laminated wing [3]

The described test was aimed at comparing the glider wing stiffness before and after the reinforcement of its skin by the single layer of carbon-epoxy laminate [10]. Measurements of deflection lines of the wing were carried out by applying the concentrated force to its end. The wing mounted on the research stand was – in all cases – loaded in the same way. Measurements were performed in the same points, along lines previously marked on the wing skin.

On the basis of static investigations it was found that the application of the modified (hybrid) reinforcement of the wing provides the essential positive change of de-

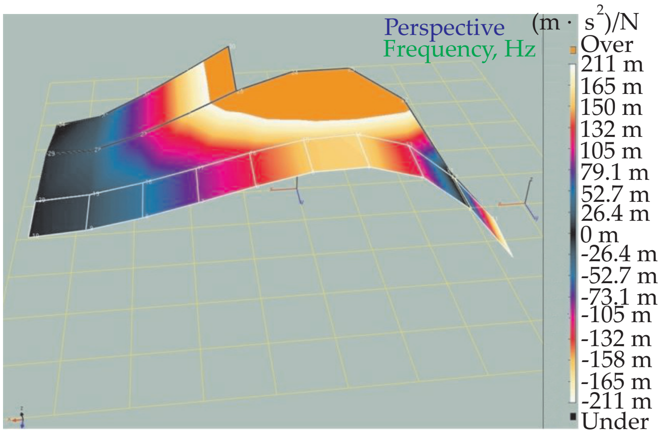

Fig. 11. Vibration response of the wing excited by the signal of the frequency of 8 Hz, laminated (hybrid) wing

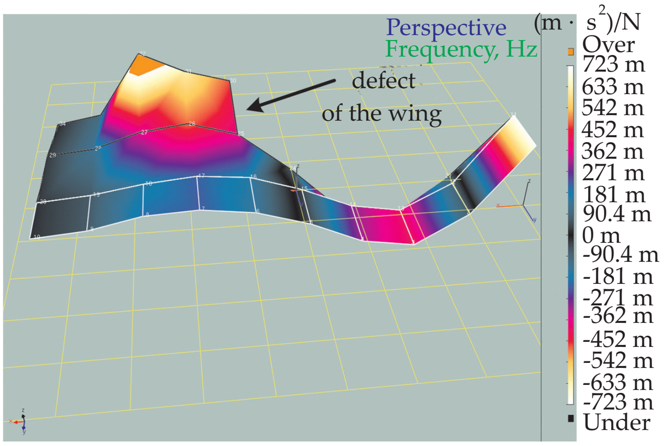

Fig. 12. Vibration response of the wing excited by the signal of the frequency of 19 Hz, laminated (hybrid) wing, the defect of the wing construction is visible in the photo [3]

formation values and of the wing deflection line on its whole length.

It was also found that damping coefficients of the structure are much higher than damping coefficients of individual materials, which were used for building this structure. This indicates that the hysteresis damping is very important in damping vibrations of the analyzed structure.

On the basis of dynamic investigations it was found that adding the carbon composite layer was significantly changing the vibration response of the object. The diagrams of the spectral response function, presented in Figs. 9 and 10, indicate significant decreases of the level of the vibrations acceleration amplitudes in the whole analyzed range as well as the strong damping of the frequency dominating for the original wing skin. This is also confirmed by the modal analysis where the significantly lower number of resonance frequencies was found in the hybrid wing than in the original wooden wing. This means less complicated forms of vibrations [11]. When there is a lower number of resonances there are wider extra-resonance bands allowing for simpler methods of damping the dominating vibrations. Due to that, it is possible to assure – in a simpler and more efficient way – the safe usage of such object.

It should be additionally emphasized that the presented method of dynamic investigations is very useful in looking for the construction defects. The presented results of the analysis of the vibration response on the excitation caused by frequency of 19 Hz revealed the defect in the construction (Fig. 12).

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