ANALYSIS OF THE FEASIBILITY OF REPLACING FABRIC SKIN IN HALF-SHELL STRUCTURAL DESIGNS

Analiza możliwości zastąpienia pokrycia płóciennego w konstrukcjach półskorupowych

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DOI: 10.15199/160.2021.4.1

Abstract: One of the many issues associated with aircraft operations is that of structural designs with fabric skin. As one of the solutions addressing these problems, this paper proposes replacing the existing fabric skin with a new covering made of a composite material. The object of analysis available to the authors was a horizontal stabilizer of Mi-2 helicopter. This paper presents the results of fatigue tests applied to the thin-walled structure of the horizontal stabilizer, carried out under two scenarios: (I) with the fabric skin removed and (II) with the composite material skin installed. During the tests, strain values were measured at selected points of the stabilizer structure, using linear type resistance strain gauges and in a rectangular rosette arrangement. The test results confirmed the feasibility of replacing the fabric skin with a composite material skin.

Keywords: aircraft, fabric skin, composite material skin, fatigue testing, strain measurement

Streszczenie: Jednym z wielu zagadnień związanych z eksploatacją statków powietrznych są problemy dotyczące zespołów konstrukcyjnych posiadających płócienne pokrycie. Jako jedno z rozwiązań tych problemów, w artykule zaproponowano zastąpienie dotychczasowego pokrycia płóciennego nowym pokryciem w postaci materiału kompozytowego. Obiektem analizy, jakim dysponowali autorzy był statecznik poziomy śmigłowca Mi-2. W artykule przedstawiono rezultaty badań zmęczeniowych cienkościennej struktury tego statecznika poziomego, przeprowadzone dla dwóch przypadków: (I) z usuniętym pokryciem płóciennym oraz (II) z zamontowanym pokryciem kompozytowym. Podczas badań dokonywano pomiaru wartości odkształceń w wybranych punktach struktury statecznika, z wykorzystaniem tensometrów oporowych typu liniowego oraz w układzie rozety prostokątnej. Wyniki badań potwierdziły możliwość zastąpienia pokrycia płóciennego pokryciem kompozytowym.

Słowa kluczowe: statek powietrzny, pokrycie płócienne, pokrycie kompozytowe, badania zmęczeniowe, pomiar odkształceń

Introduction

Airframes of aircraft are most often manufactured as half-shell structures [1,2,11]. A characteristic feature of such structures is that individual airframe components are made of metal, mainly aluminum alloys. Due to the type of materials, riveting is the most common method of making connections. However, despite the passage of time, aircraft whose assemblies - primarily the stabilizers - are made as half-shell structures with fabric skin are still in service.

Fabric was used extensively in truss airframes due to the fact that it was the only material available that was suitable for use as a skin due to its density. The passage of time caused the number of aircraft with fabric skin to decline steadily, limiting the use of fabric to special aircraft, vintage aircraft and gliders, etc. [4] At the same time, this caused a drastic decrease in qualified personnel whose skills would allow them to perform work related to the replacement of fabric skin, or repair their damage. Against all appearances, replacing the skin is a very tedious and complicated process that also requires manual skills from the contractors. Fabric skin also requires exercising care during aircraft operation, as it can be easily damaged (e.g., torn). Fabric skin exposed to external factors, i.e. UV light, moisture, dust and even biological agents (moulds and algae), age quickly and need to be replaced.

Recognizing the problems associated with the operation of airframe assemblies covered with fabric, especially given the absence of personnel and time-consuming replacements, it was decided to see if it was possible to replace the fabric skin with another material, i.e. composite material.

Test object

A typical example of a metal, half-shell structure with a single-circuit caisson with a skin that is flexible (made of fabric) outside the caisson is the horizontal stabilizer of the Mi-2 helicopter (Fig.1). Therefore, it was decided to use this team to study the feasibility of a new skin material [7].

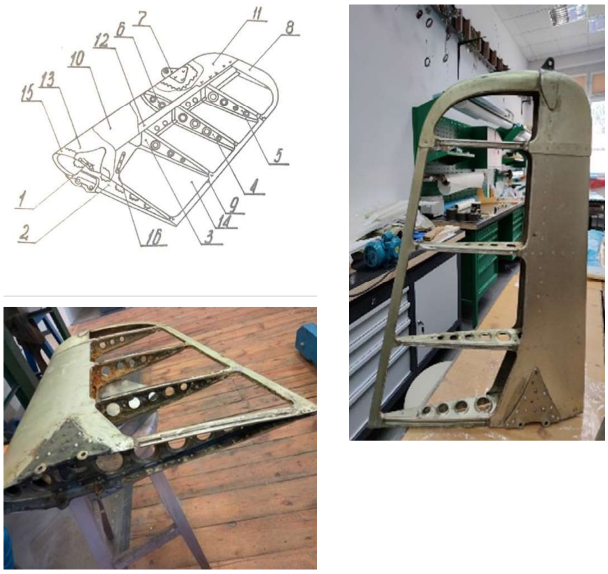

Fig. 1. Stabilizer design [7] [Photo S.Tkaczuk]: 1- cover plate; 2- rib No. 1; 3- rib No. 2; 4- rib No. 3; 5- rib No. 4; 6- rib No. 3; 7- pylon; 8- section; 9- rear strip; 10- metal skin; 11-terminal fairing; 12-truss; 3,14- fabric skin; 15- percale band; 16-countersunk rivet

Analyzing the design of the stabilizer and the method of connecting the fabric to the framework, a simple replacement of the fabric with aluminum alloy sheeting was ruled out. This was not possible due to the design of the rib racks preventing the use of rivets to connect the covering to the rib.

A proposal was made to replace the fabric with a composite material and in the the first phase of work an sandwich structure of glass composite and Herex foam was used. Glass composite has properties similar to those of fabric skin - it is strong and flexible.

The composite material skin (Fig. 2) was made as a single component consisting of an upper and lower covering plate and a runoff element connecting the two plates into a single unit. Each cover plate consists of two layers of E91 glass fabric infused with resin, with Herex foam sandwiched between them - resulting in a sandwich design [3]. The application of foam was intended to make the cover plates rigid in the rib spacing. The base in the composite material was LR285 epoxy resin + H285 hardener [6].

Fig. 2. The top plate of the stabilizer cover and the interior of the new stabilizer cover [Photo S. Tkaczuk]

The covering element prepared in this way was glued to the stabilizer skeleton. The component was glued directly to the caisson plate and racks of rib No. 1 and the trailing edge, while for the other ribs, i.e., No. 2, No. 3, and No. 4, were glued through the composite cladding with which they were previously covered. In addition, along the edge of the caisson at the height of each rib, the composite element was riveted with one-sided rivets

Experimental tests

Considering the load fatigue of helicopter airframes, the study was limited to fatigue tests comparing the stabilizer strain without and with a composite skin after a specified number of fatigue cycles.

• Measurement system

It was decided to perform strength tests of the horizontal stabilizer without skin and with a glued composite element replacing the fabric skin.

The scope of the test was to perform 500,000 load cycles with a displacement of 4.5 mm (equivalent to a force of 1.25 kN) and a frequency of 0.42 Hz. The assumed load value corresponded to the value of the aerodynamic force generated by the horizontal stabilizer [10] calculated for a Mi-2 helicopter flying at 190 km/h [12].

The fatigue tests were conducted on a fatigue test bench consisting of a loading system and a strain gauge bridge system with a CL 460 multi-channel recorder for recording measurements from the resistance strain

Fig. 3. Test bench [Photo by S. Tkaczuk]

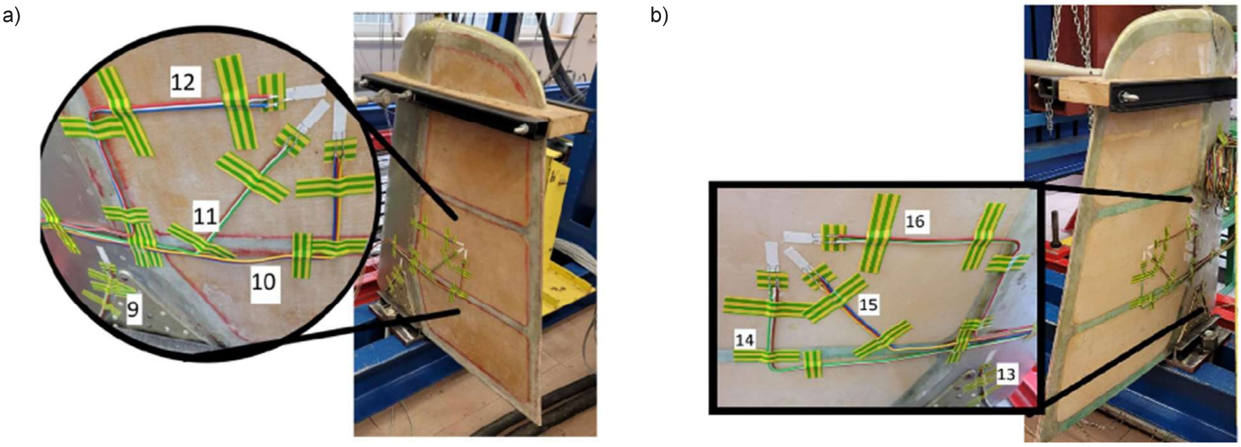

Fig. 4. Distribution of strain gauges on the skin: a) top skin, b) bottom skin [Photo. S. Tkaczuk]

gauge system. The elements of the test bench discussed are shown in Figure 3.

The strain gauges were placed on both sides of the stabilizer: in a linear arrangement on the surface of the caisson's cover plate (at the height of the truss wall) and in a rectangular arrangement, in the center of the area between ribs No. 2 and No. 3 (Fig. 4) [9].

Measurements were take under two scenarios: I) load on the structure with the fabric skin removed and II) load on the structure with the composite skin installed.

Scenario I. Loading of the structure with the fabric skin removed

Test conditions:

During this test, the oscillations of the stabilizer were investigated in a zero pulsating cycle, i.e. the value of deviation from the neutral position was +4.5 mm (Fig. 5). Channel 13 refers to the strain gauge on the lower surface of the stabilizer, while Channel 9 indicates the values read by the strain gauge compressed on the upper surface of the stabilizer (Table 1).

Table 1. Strain registration parameters for the initial 0 cycles - before the start of the fatigue test [own analysis]

	Bottom stabilizer surface	**Top stabilizer surface**
	Channel 13	**Channel 9**
Min. value. [µm/m]	-20	-477
Max. value. [µm/m]	501	19
Registration of duration period [s]	77.4	77.4
No. of samples	872	872

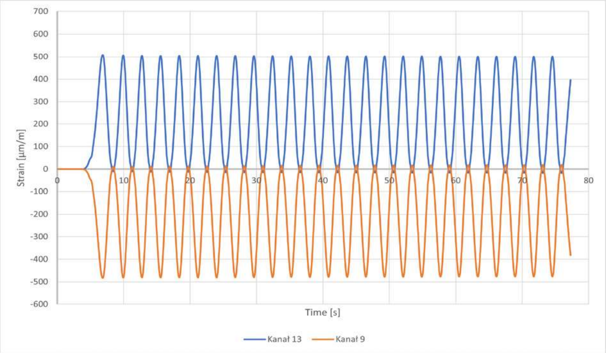

Fig. 5. Diagram of strain changes over time: Channel 9 - strain gauge on the top surface of the stabilizer, Channel 13 - strain gauge on the bottom surface of the stabilizer [own analysis]

Scenario 2. Loading of structure with composite skin installed.

Strain gauge measurements

In this fatigue test, channels numbered 9 through 12 of the CL460 Multi-Channel recorder corresponded to strain gauges on the upper surface of the stabilizer, while channels numbered 13 through 16 indicated the values read by the strain gauges on the lower surface of the stabilizer.

Measurement results

Not knowing exactly how the new composite skin under test would behave during the test, such as whether localised peeling would occur from the dural framework of the stabilizer, the entire test was divided into stages of 50,000 cycles each. After the completion of each such step, strain values were recorded for all eight (8) strain gauges [8].

As examples, Table 2 shows the recorded parameters for a run of 0 cycles, while Table 3 shows the recorded parameters for a run of 500,000 cycles. The waveforms

Table 2. Strain registration parameters for the initial 0 cycles - before the start of the fatigue test [own analysis]

	Top stabilizer surface					Bottom stabilizer surface				
Measurement case	**I.**	**II.**				**I.**	**II.**			
Channel No.	9	9	10	11	12	13	13	14	15	16
min. [μm/m]	-477	-522	-100	-470	-55	-20	-5	-13	-19	-13
max. [μm/m]	19	3	-9	-5	-7	501	539	368	659	157
Registration of duration period [s]	77.4	61.8	61.8	61.8	61.8	77.4	61.8	61.8	61.8	61.8
Value in absolute terms [μm/m]	496	525	91	465	48	521	544	381	678	170

Table 3. Parameters for recording strains for 500,000 cycles – after completion of the fatigue test [own analysis]

	Top stabilizer surface					Bottom stabilizer surface				
Measurement case	**I.**	**II.**				**I.**	**II.**			
Channel No.	9	9	10	11	12	13	13	14	15	16
min. [μm/m]	-477	-334	-16	32	-1	-20	-398	-18	0	0
max. [μm/m]	19	145	58	479	54	501	86	336	619	73
Registration of duration period [s]	77.4	61.4	61.4	61.4	61.4	77.4	61.4	61.4	61.4	61.4
Value in absolute terms [μm/m]	496	479	74	447	55	521	484	354	619	73

for the number of cycles 0 and 500,000 are shown in Figures 6 and 7.

A comparison of the results obtained on Channels 9 and 13 (Table 2 and Table 3) shows that the absolute values of the measurements made for both measurement cases analyzed are of the same order. For this type of strain gauge measurement, differences in readings as small as tens of μm/m are treated as insignificant because they occur at the fifth decimal place. The results obtained allow us to conclude that the use of composite as skin of the tested stabilizer did not change the values of deformation of the structure. Comparing the strain values recorded at the beginning of the fatigue test (for 0 cycles) with the strain values measured after the end of the test (for 500,000 cycles), there were also no significant differences in the strain values (Table 2 and Table 3).

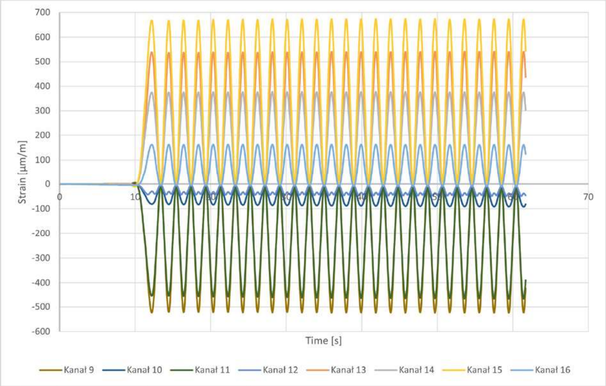

Fig. 6. Graph of strain changes over time for the initial 0 cycles - before fatigue testing: Channels 9-12 - strain gauges on the top surface of the stabilizer, Channels 13-16 - strain gauges on the bottom surface of the stabilizer

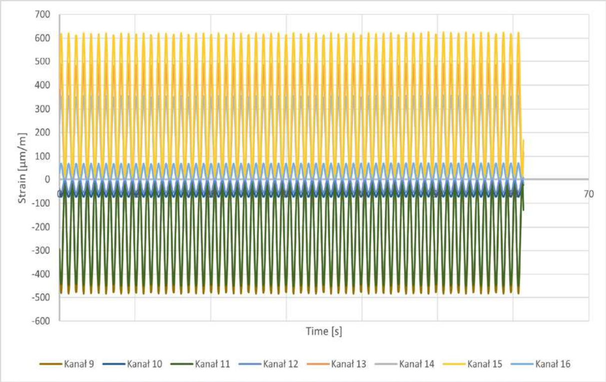

Fig. 7. Graph of strain changes over time for the final 500,000 cycles - after the end of the fatigue test: Channels 9-12 - strain gauges on the top surface of the stabilizer, Channels 13-16 - strain gauges on the bottom surface of the stabilizer

Major strains

From the strain values measured by rectangular strain gauge rosettes, for each stage of 50,000 fatigue cycles, the maximum and minimum major strains, expressed by the following formulas (1) (2) [5], were calculated:

$$\varepsilon_{max} = \frac{\varepsilon_0+\varepsilon_{90}}{2} + \frac{\sqrt{2}}{2} \cdot \sqrt{(\varepsilon_0 - \varepsilon_{45})^2 + (\varepsilon_{45} - \varepsilon_{90})^2} \tag{1}$$

$$\varepsilon_{min} = \frac{\varepsilon_0+\varepsilon_{90}}{2} - \frac{\sqrt{2}}{2} \cdot \sqrt{(\varepsilon_0 - \varepsilon_{45})^2 + (\varepsilon_{45} - \varepsilon_{90})^2} \tag{2}$$

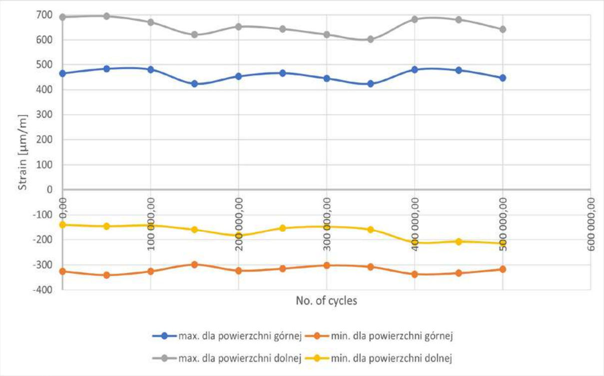

Fig. 8. Values of maximum and minimum major strains

Table 4. Values of maximum and minimum major strains for successive stages of fatigue testing [own analysis]

	Major strains			
	Top surface of stabilizer		**Bottom surface of stabilizer**	
No. of cycles	**max. [µm/m]**	**min. [µm/m]**	**max. [µm/m]**	**min. [µm/m]**
0	465	-326	691	-140
50.000	483	-341	694	-146
100.000	480	-326	670	-143
150.000	424	-299	621	-160
200.000	453	-323	652	-183
250.000	466	-315	643	-154
300.000	445	-302	621	-148
350.000	424	-308	603	-160
400.000	479	-337	681	-211
450.000	477	-333	680	-208
500.000	447	-318	642	-215

The results of these calculations are shown in Table 4.

The results collected in Table 4 are presented graphically in the summary Figure 8. The figure shows the maximum and minimum values of the calculated major strains. The values of maximum major strains were recorded on the skin of the bottom surface of the stabilizer in tension, whereas the values of minimum major strains were recorded on the skin of the top surface of the stabilizer in compression.

Conclusions

Based on the obtained results of fatigue tests of the horizontal stabilizer of Mi-2 helicopter, it was concluded that:

1. The use of a skin made of glass composite reinforced with Herex spacer did not enhance the rigidity of the stabilizer.
2. The results obtained during the carried out tests fully confirmed an option of replacing thefabric skin with a composite material skin.
3. There was no increase in the strain values of the skin itself compared to the strain values measured prior to the fatigue tests.
4. If the fabric skin was replaced with a composite material skin, the service life of this structural assembly would probably be extended. However, the authors of this paper are unable at this stage to determine precisely by how many calendar years or operational hours.

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