Analysis of Fatigue Cracks Propagation In Complex Structures

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Abstract: *The paper presents the broad study of the fatigue damage of plane wing and its fragments. The point-site, multiple-site, multiple-element and widespread fatigue damage were taken in consideration. It was observed that the design changes could be linked with damage specification. In the case of the object with WFD (Widespread Fatigue Damage) the new designs were applied. When the object did not show WFD type of damage the changes, which improved the only geometry of the designs, were introduced.*

1. INTRODUCTION

The paper deals with the analysis of the various types of cracks in the structure of PZL I-22 Iryda plane wing, which have been revealed during the fatigue tests. The analysis were performed with following criteria assumed: number of damaged point, elements, size of the damaged area and the cracks propagation speed.

Assumed the criteria are closely linked with the damage tolerance – the attribute of a structure that permits it to retain its required residual strength for a period of usage after the structure has sustained specific levels of fatigue, corrosion, accidental or discrete source damage. Here are the necessary keywords [1, 4]:

Multiple Site Damage (MSD) – simultaneous fatigue cracks in the same structural element,

Multiple Element Damage (MED) – simultaneous fatigue cracks in the similar adjacent structural elements,

Widespread Fatigue Damage (WFD) – simultaneous fatigue cracks in multiple structural elements of so considerable measures and density that the structure has lost its tolerance to the cracks. WFD would own MSD or MED character.

2. OBJECTS AND RANGE OF FATIGUE STUDY

The object of the broad study program was the wing of PZL I-22 Iryda plane

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[5]. Iryda is tandem-seat advanced training/combat subsonic jet plane. The plane enables to realize the full training program including pilotage, navigation, battle, battlefield reconnaissance and, the ground and sea borne targets. The trapezoid wing of the plane was designed as one peace of +14.5^0 sweep back (at 25 % of wing chord) and 3^0 anhedral. The profile varying along the wing with -1.7° geometric twist. The wing is mostly high-strength light alloy made with limited use of steel and composite elements. The base of wing structure element is the central torque box created by the front and rear spars and reinforced with the stringers upper and lower skins. For technological reasons the mono-part wing was divided into three sections i.e. the central wing and outer ones. The separation takes place on the rib No 9aL/P. Moreover, at the lower skin close to the 5L/P rib the cross fastening of skin sheets were introduced. The detailed strength characteristic of wing has been shown in the work [6].

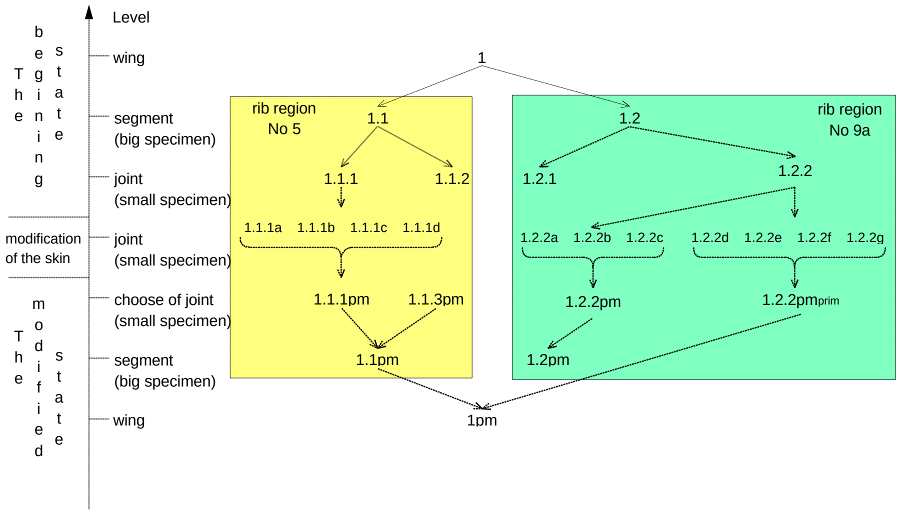


Fig. 1. Systematic of marking of test objects: a, b, c, ... – mean consecutive modifications, pm – mean the object after modification.

The full-scale fatigue test of the wing was followed by the preliminary tests of its fragments. During the study course the attention was stressed on to the lower skin of wing, as at this area the tensile stresses were dominant. Particular attention was focused on to the area at which the fatigue crack origination is the most probable. The skin was decomposed into the fragments, which covered as well the bigger (the segment) as the smaller areas (the specimens). The specimens contained one structural joint. Segments length was of 1920 mm, and specimens - 530 mm. The fatigue study included 4 types of segment, 19 types of specimens (64 objects in all) [7]. The number of objects implied the necessity of a special systematic application (see Fig. 1) which creates possibility to estimate of the mutual relations between the objects (see Fig. 2).

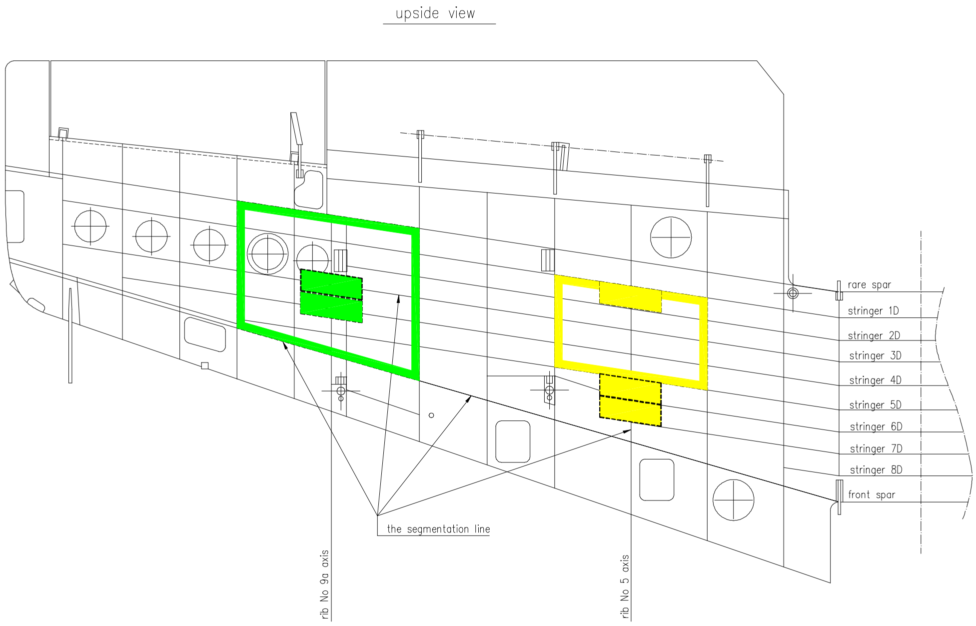


Fig. 2. The positions of segments and specimens at the wing scheme.

Problem concerning the loading spectrum selection is described in [6]. The loading spectrum of Hawk training jet plane was accepted as the base for the Iryda wing. During the study the series of the loading block programs has been elaborated. These programs have contained the “progressively-ascending-diminishing” and “flight-by-flight” sequences.

3. FATIGUE DAMAGE OF THE TESTED OBJECTS

The fatigue testing covered of 64 objects. Fatigue fractures were carefully examined with macro- and micro-fractography methods. The point-site, multiple site (MSD), multiple element (MED) and widespread fatigue damages (WFD) of the objects were observed. Below could be found the examples of the specific kinds of damages, being the results of the macro-fractographic testing.

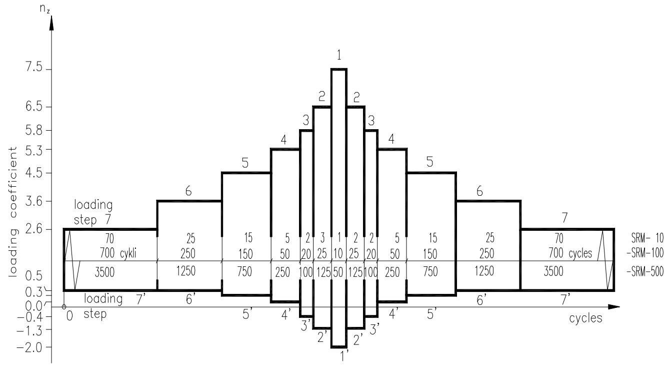
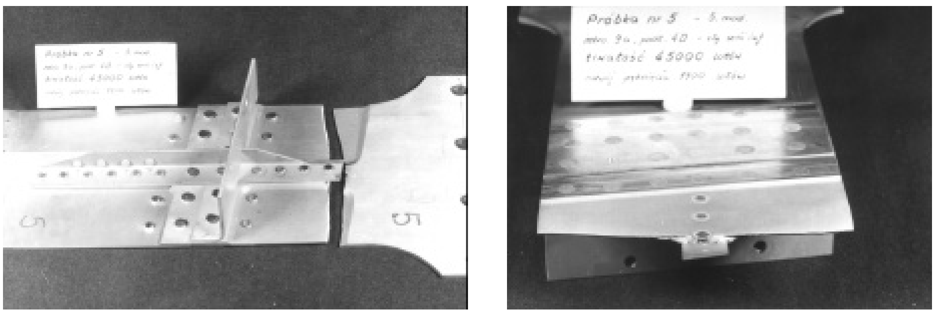


Fig. 3. Loading sequence in programs SRM-10, SRM-100 and SRM-500

The point-site damages were observed in the skin specimens numbered 1.1.2, 1.2.2c, 1.2.2d, 1.2.2e, 1.2.2f, 1.2.2g, 1.2.2pm and 1.2.2pm$_{prim}$. In those specimens the cracks occurred in the skin were originated at the rivet hole, where the skin is connected with the stringer. The good example of this type of damage could be specimen 1.2.2pm$_{prim}$ shown in Fig.4. The crack occurred in right skin in the section of the last rivet (nearest to rib No 9) at connection of the stringer link with the right hand skin.



a b

Fig. 4. The course crack in specimen 1.2.2pm$_{prim,}$ a – view from the stringer site, b – the fracture.

The multiple site damage occurred in specimens 1.1.1pm, 1.1.3pm, 1.1.2.2, 1.2.2a, 1.2.2b and segment 1.2. The course of crack in specimen 1.2.2 was shown in Fig. 5a. The lower skin sheet has fracture along a zigzag pattern situated in between the rivets linking it with the upper skin sheet. The analogous course of the fracture took place in segment 1.2 what is in show in Fig. 5b. This type of the damage has also occurred in the wing after modification (1pm) in the wall of front wing spar. The cracks originated at the bigger hole for the fuel sensor, Fig. 6 [3, 6]. The cracks started at two holes of severe fastening of the fuel sensor.

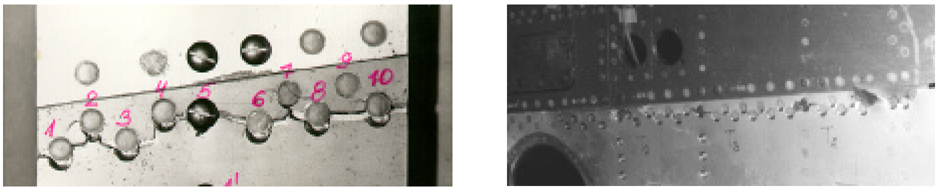


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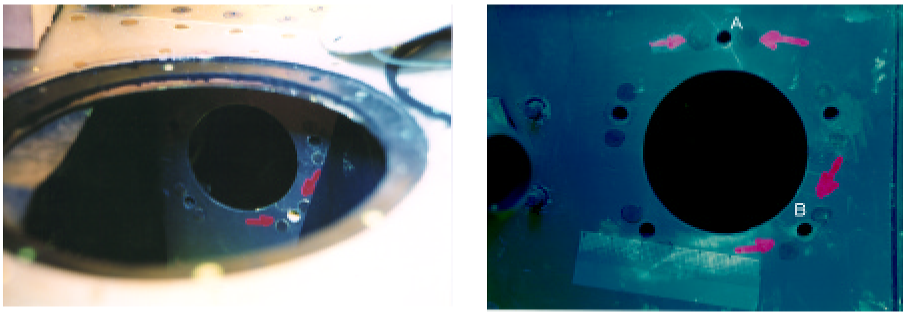
Fig. 5. The course of crack propagation, a – in specimen 1.2.2, b – in segment 1.2.



a b

Fig. 6. The course of crack in wing front spar revealed with luminescent-penetrate method (after disassembling of the fuel sensor), a – seen through the opening in nose skin, b – after disassembling of nose skin (UV picture).

The multiple element damage occurred in specimens 1.1.1, 1.1.1a, 1.1.1b, 1.1.1c, 1.1.1d, 1.1.1pm, 1.2.1 and, in segments 1.1, 1.1pm, 1.2, 1.2pm and $1.2pm_{prim}$. In specimen 1.1.1d the fatigue cracks occurred at left skin (see Fig. 7a) and at the upper stringer (see Fig. 7b) [6]. Whereas in 1.2pm case (see Fig. 8) the fatigue cracks occurred at the hatch frames, the circular and oval, and at the skin and stringer 1D [6].

The second *multiple element damage* of wing 1pm [2,6] has the nature of *widespread fatigue damage*. The skin crack was accompanied (see Fig. 9) by the fractures of the rear spar (see Fig. 10a), stringers 1D (see Fig. 10b) and 2D. The full wing destruction was avoided by precise positioning of the limiters of the actuators. Also, WFD character had MED of specimen 1.2.1 and**,** MSD specimen1.2.2 (see Fig. 5a) and segment 1.2 (see Fig.5b).

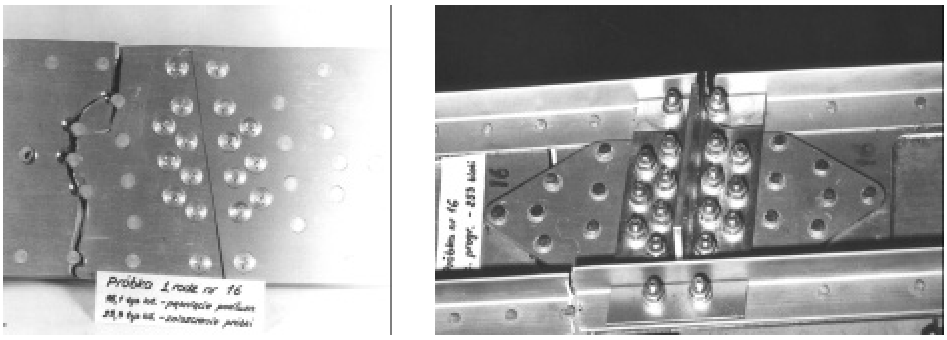


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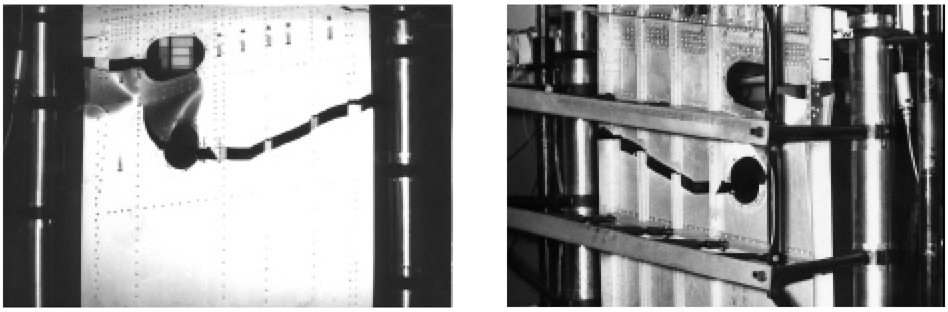
Fig. 7. The crack course in specimen 1.1.1d, a – the skin side view, b – the stringers side view.



a b

Fig. 8. Crack propagation in segment 1.2pm, specimen No. 5, a - seen from skin side. The crack originated at the rear spar propagates up to the oval hatch frame. The skin between the oval and circular hatches lost of its stability. The crack originated at the circular hatch ends at the front spar. b - stringers side view.

4. CONCLUSIONS

The analysis of specimens fatigue cracks in the samples allows finding a new approach to the required changes that should be introduced into the design. For specimens with *widespread fatigue damage* the completely new design concepts were applied. When it was not the *widespread fatigue damage* case then the changes in the design concerned geometric features of the existing structure only.

In paper [2] the influence of geometric design features on the fatigue durability of the objects tested were analyzed. On the analysis of the results base the changes in the designs which led to increase in its durability were introduced [6, 7]. For example, the durability of specimen 1.1.1pm has increase five times if one compare it with sample 1.1.1 durability, whereas at the specimen 1.2.2pm$_{prim}$ case the increase was eighteen times against the sample 1.2.2.

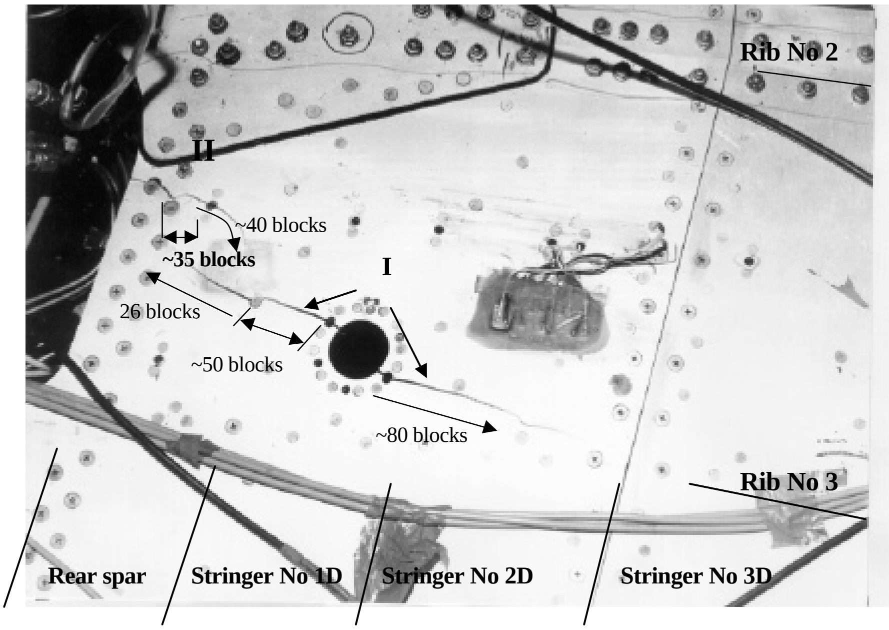
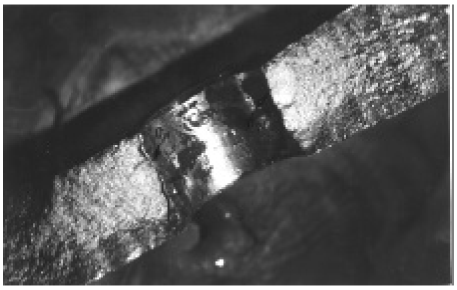


Fig. 9. Illustration of the crack propagation between ribs Nr 2 and 3 in left wing skin.



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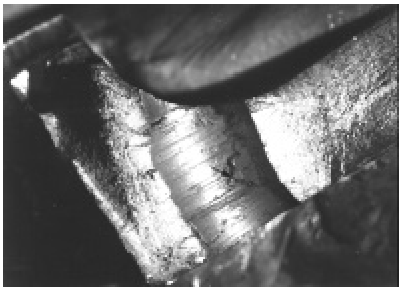

b

Fig. 10. The fractures at: a – rear beam, b – stringer nr 1D

The cases of complex fatigue cracks present the difficult problems both for the analysis and the testing. The existence of multiple origins of the cracks and their differential courses and propagation speed significantly influence the re-distribution of loading of the complex aeronautic structures. FEM calculations assume creating a lot of the computational models. The analyst area represents the contact between the fracture mechanics and the fatigue of construction. Random nature of fatigue phenomena additionally complicates the matter. Apart from the direct probabilistic models the Monte Carlo methods could be also applied.

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