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PREDICTION OF WFD OCCURRENCE IN LONGITUDINAL JOINTS OF A FUSELAGE FOR COMMERCIAL AIRPLANE

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Abstract

The probabilistic model of durability until the occurrence of first cracks in areas with equals stress range of longitudinal joints of the wing and aircraft fuselage is presented in this paper. The probabilistic model includes the method of obtaining the S-N curve for cracks of necessary length in elemental area that includes one typical stress concentrator for longitudinal joint of wing or fuselage. Initial data for model that is presented in this paper one can obtain after fatigue testing of fuselage panels with longitudinal joint that were manufactured by commercial technology with detailed fractography analyses of longitudinal joints after testing. The proposed probabilistic model allows to choose optimal geometrical, technological parameters and specify allowable stress-strain state in the longitudinal joints, taking into account the quantities of stress concentrators of the single-type. Using presented probabilistic methodology is possible to predict the appearance of WFD in the longitudinal joint of the fuselage.

1 Background Information

To ensure safety of aircraft structure with the ever-increasing requirements to increase lifetime primarily one had to pay attention for modifying areas with different irregularities that include stress concentrators that operate under complex stress-strain state. According to the results of tests of aircraft structures on stands and during the endurance test has become necessary to increase the fatigue strength of regions with irregularities (for example, longitudinal joints of the wing and the fuselage, cutouts for inspection and assembly, openings for fuel overflowing, etc.). Improvements have led to an increase in lifetime especially for critical elements; such elements as usual define the properties of lifetime of the aircraft. Much attention was paid also to improve the fatigue and residual strength properties of aircraft materials, fasteners, manufacturing procedure of joints. Despite efforts to improve the materials and manufacturing techniques of the compounds in 90-ies of the last century during the endurance test began to show up cracks in the longitudinal joints of the wing, and after disassembling longitudinal seams on the endurance test termination were found numerous small cracks caused by holes for rivets. This paper deals with the probabilistic justification of safe lifetime of longitudinal seams and joints in continuous operation. Namely numerous elementary stress concentrators, distributed practically over the entire surface of the aircraft, which occupy a significant part of its area, and have the greatest impact on lifetime properties and the design weight, currently require special attention to ensure the safety for long term operation with minimal loss of efficiency. The requirements to lifetime of modern aircraft have increased several times, more than 50 000 flights and approaching 100,000 flight hours is normal lifetime for commercial airplanes, which makes necessary to pay particular attention not only on lifetime of the longitudinal joints of the wing, that determine aircraft weight, but also on the lifetime of the longitudinal joints of the fuselage, where multiple cracks could lead to catastrophe. To formulate a probabilistic model a few definitions is introduced:

- The length of the sections of discrete compounds stiffeners to skin using fasteners or cladding panels to each other will be referred to a regular zone (RZ).

- Elementary RZ area with one typical stress concentrator - will be called the isolated element (IE).
- One can consider IE as one type and call them homogeneous IE, if the strength properties of the materials for the parts to be joined, coatings, the geometrical properties, heat treatment, surface treatment, types of fastening elements, installation technology and etc., for the group of IE coincide.

Design of RZ in terms of fatigue resistance is reduced to the terms of the optimal choice of geometric characteristics and allowable stress-strain state. Design of RZ of fuselage should be aimed primarily at ensuring the maximum durability without cracking (safe-life approach with a given probability), and then on the development of criteria for residual strength calculation taking into account the probabilistic model for further propagation of cracks, their mutual influence and reduction of the residual strength. Up to date during the design and the choice of design and technological solutions RZ as the calculated curves is used the average S-N curve obtained by the results of tests of open hole specimens and full-scale fuselage panels or panels that structurally similar with full-scale panels. To optimize the weight and allowable stress-strain state when designing RZ in terms of fatigue resistance must be selected taking into account the geometric characteristics taking into account amount of homogeneous IE in RZ, as the amount of IE influences on durability before the initiation of first crack is very large and depends on the scattering of the logarithm of durability. This influence can be seen in Figure 1, which shows the dependence of the mean value of the logarithm of durability to the occurrence of a crack in one area IE to the average value of the minimum of n IE. For values of standard deviation of the logarithm of durability IE from 0.1 to 0.25 and n = 1000 IE ratio is from 2.11 to 6.46. Thus, 2.11 times can decrease the durability before the first crack at the section with 1000 the same type stress concentrators in the scattering of 0.1, but such regions may be as many as planes in the park and on each crack may occur earlier.

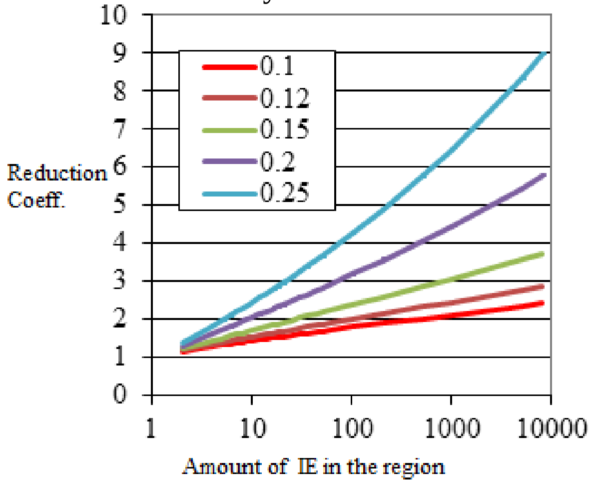

Fig.1. Dependence of ratio of the average durability of IE to the average of the minimum durability from n IE.

2 Probabilistic model of durability for wing and fuselage

2.1 General Information

The concept of probabilistic model of durability and service life of the so-called "a multi" of the aircraft structure, taking into account the variety of stress concentrators in the design was considered in [1]. In [2], a probabilistic model of durability RZ wing and showed good agreement made on this model durability prediction before the first cracks in the longitudinal seam of a civilian aircraft during the endurance test. To obtain a probabilistic model of the durability of the wing or fuselage RZ concrete aircraft must first perform a preliminary calculation of the equivalent stresses for the typical flight in region of IE for whole RZ of concrete component. As an example, Figure 2 shows the distribution of the equivalent stress at the lower surface of a wing of passenger aircraft.

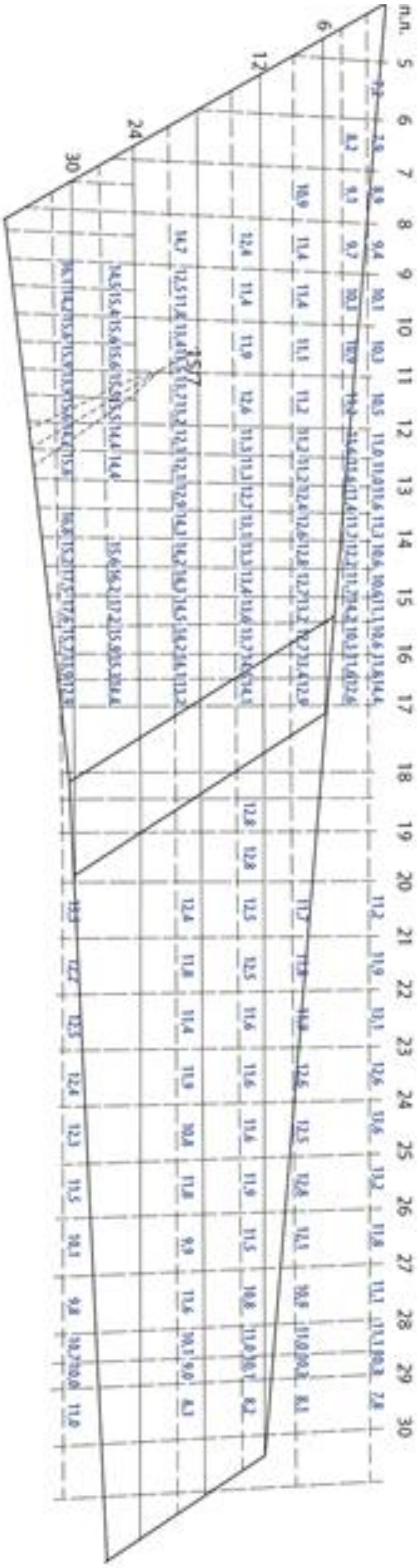

Fig.2. The equivalent stresses at the lower surface of a wing

Table 1 represents the same data, where such areas are combined under one counting number. To perform a more precise calculation the equivalent stresses on such sites should be counted with greater accuracy. The table shows that the total number of areas in the above example - 23, the total number of IE - 15138, the range of stresses from 7.5 to 17.6 *MPa*, the scatter of IE in areas from 80 to 1840. For most areas the difference in the stresses within the area of IE no more than ± 2.5 *MPa*.

Table 1 Areas with equal equivalent stresses and different amount of IE

№ п/п	σ_{eq} *MPa*	n_i (IE)
1	75	278
2	82	790
3	92	390
4	99	702
5	104	742
6	109	1054
7	112	1152
8	115	1840
9	118	1550
10	1,2	520
11	125	1626
12	128	770
13	132	638
14	135	416
15	139	349
16	143	752
17	146	212
18	153	443
19	157	534
20	162	113
21	168	107
22	172	80
23	176	80
$\sum n_i$		15138

As for fuselage, on Figure 3, one can see typical areas of IE (longitudinal joint), as usual the stress levels for all regular area are the same and equal approximately 90-110 *MPa* [3].

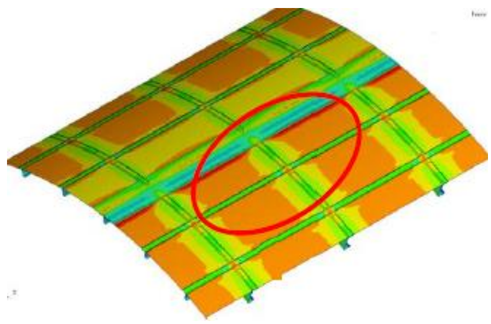

Fig.3. Areas of equal equivalent stresses of the fuselage

The main difference between fuselage and wing, that the one of the most critical area of the fuselage (longitudinal joint) has approximately constant equivalent stress along the fuselage for each IE unlike the wing.

Formulation of RZ in the form of areas containing different numbers of IE, allows us to define the distribution function sharing durability of the section of RZ (DFDs), knowing the distribution function of durability for area with one IE (DFDi). We accept the following assumptions, which are natural and passed tests for samples using statistic criteria.

- Durability of the appearance of crack of length *l* mm in area of IE - independent random variable. More detailed this approach was described in [4].
- Durability of the segment of RZ with equal stresses in the segment and homogeneous IE assumed durability before the first crack in one of the area of IE.
- Assumed, that DFDi has logarithmically normal distribution (1), parameter estimates a_{lgN} and σ_{lgN} of this function we get by the results of tests of full-scale panels with segments of RZ (wing) or by the results of a quantitative-fractography after the testing of the panels that simulate the segment of longitudinal joint of the fuselage.

$$F_{ei}(lgN, a_{lgN}, \sigma_{lgN}) = \frac{1}{\sqrt{2\pi}\sigma_{lgN}N}\int_{-\infty}^{\frac{lgN-a_{lgN}}{\sigma_{lgN}}} e^{-\frac{t^2}{2}}dt \qquad (1)$$

- Values of DFDi parameters depend on the type of IE and depend on the level of the equivalent stress at the segment.

Under these assumptions, in accordance with the hypothesis of a "weak link", the distribution function of the durability before the first crack at the *i-th* section of the RZ and for the whole RZ can be written as follows (2), (3):

$$F_{yi}(lgN, a^i_{lgN}, \sigma^i_{lgN,} n_i) = 1 - [1 - F_{ei}(lgN, a^i_{lgN}, \sigma^i_{lgN})]^{n_i} \qquad (2)$$

$$F_{RZ}(lgN, \Theta_a, \Theta_{s,} n_i, k) = 1 - \prod_{i=1}^{k}\left(1 - F_{ei}(lgN, a^i_{lgN}, \sigma^i_{lgN})\right)^{n_i} \qquad (3)$$

2.2 Initial data and experiments for probabilistic model for longitudinal lap joint of the fuselage

There are two types of the initial data:

- Test results of the longitudinal lap joints (samples). The example of such tests is presented in work [5]. The external view of the such sample is shown on Figure 4.

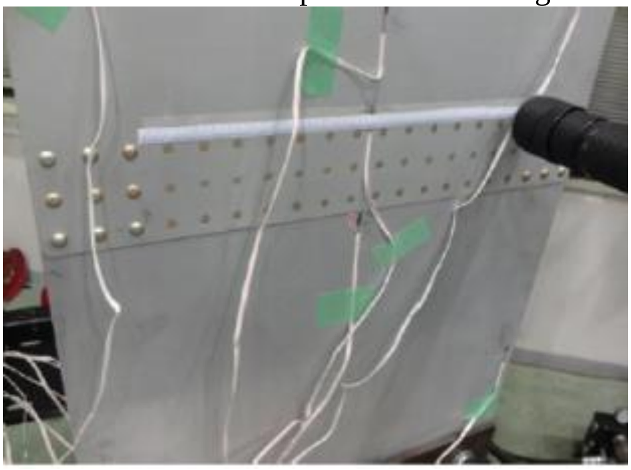

Fig.4. The sample of longitudinal joint of the fuselage

- Test results of the full-scale fuselage panels. The example of such tests is presented in work [4]. The external view of the such panels is shown on Figure 5.

Fig.5. The example of full-scale fuselage panels

After tests the longitudinal lap joint must be unriveted and need to be carried out numerical fractography. The typical result of the numerical fractography is shown on Figure 6.

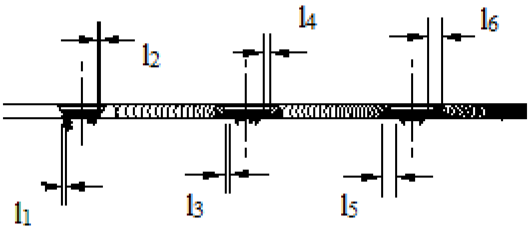

Fig.6. Typical result of numerical fractography

For several segments of the lap-joint one need to obtain crack growth period by fractography. As usual crack propagation data has good correlation with exponential dependence. Example of approximation of experimental data is shown on Figure 7.

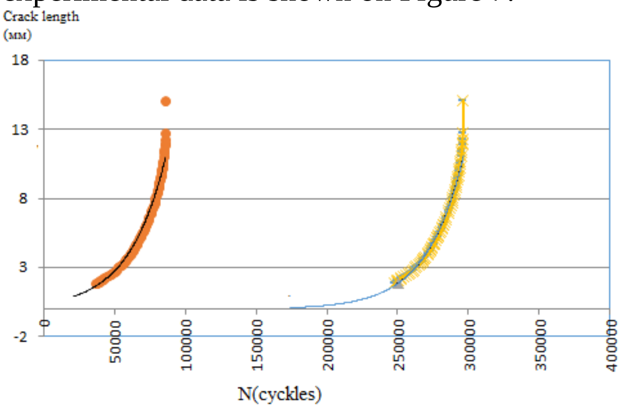

Fig.7. The example of approximation of the experimental data for crack growth period

In this chapter all initial data that needed to use probabilistic model are presented.

4 Conclusions

In this paper we presented first stage of the development of our probabilistic model and the main ideas that underlie in our model.

This model will be used to prevent and predict WFD occurrence in longitudinal lap joint in the fuselage of commercial airplanes.

Depending on the experimental data, we can predict life time of the fuselage before the occurrence of the first crack with particular length.

In future works, the numerical results of calculations will be presented.

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