METHOD FOR EVALUATION OF POSSIBILITY TO PROLONG SERVICE LIFE ON THE BASIS OF SELECTIVE INSPECTION RESULTS

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ABSTRACT

The method of selective inspection planning for determination of the possibility to prolong structural life is proposed. Using two airframe elements of AN-24 airplane, the computation of the selective inspection parameters is illustrated. It is shown that at the reliably detectable crack length ℓ_o = 0.5 mm, it is necessary to inspect the first element on three airplanes and the second one on six airplanes.

KEYWORDS

Safe life, crack growth rate, selective inspection, sample size.

To prolong the airframe life beyond the established value, it is necessary to carry out the additional activities, ensuring the safety of further operation for structural elements not to be accessed at inspection. One of the undertaking is the repair of all airplanes in the fleet. The alternative is the selective inspection with partial disassembly. The method of evaluting parameters of such selective inspection is presented in this paper. Let us consider the procedure of specifying the safe life according to the Airworthiness Regulations (1985). The safe life, N_γ^B, is defined as

$$N_\gamma^B = \bar{N} / \eta_\Sigma , \tag{1}$$

where $\bar{N}$ is the average life; η_Σ is the safety factor. In its turn the safety factor η_Σ is the product of four factors:

$$\eta_\Sigma = \eta_1 \cdot \eta_2 \cdot \eta_3 \cdot \eta_4 , \tag{2}$$

where η_1 is the factor to take account of inaccuracy in the loading determination (η = 1 - 2); η_2 is the factor, accounting the accessability of structural elements (for nonaccessible elements, η_2 = 1.2); η_3 allows for scatter of loads in the aircraft fleet (the maximum value of η_3 is equal to 1.5); η_4 is the factor, allowing for the fatigue property scatter. The factor η_4 can be presented as a product of two factors:

$$\eta_4 = \eta_4^{(0)} \cdot \eta_4^{(z)} \qquad (3)$$

where $\eta_4^{(z)}$ refers to the fatigue life scatters and $\eta_4^{(0)}$ accounts for the possible error in the average value determination. At the standard value of the root-mean-square (RMS) deviation of the service life σ =0.15 the value of $\eta_4^{(0)}$ depends on the amount of tests, m (m =1...6), and ranges from 1.2 to 1.58.

Thus, the procedure of safe life definition reduces to correction of the average service life (obtained at the fatigue testing of airframe) through the factors $\eta_1, \eta_2, \eta_3, \eta_4^{(0)}$:

$$\bar N^{(k)} = \bar N / (\eta_1 \cdot \eta_2 \cdot \eta_3 \cdot \eta_4^{(0)}), \qquad (4)$$

(where $\bar N^{(k)}$ is the corrected average life)
and to the determination of life, at which the damage probability does not exceed the prescribed value

$$N_z^{6} = \bar N^{(k)} / \eta_4^{(z)} \qquad (5)$$

When considering the conditions to be met to prolong the service, three situations are possible:
1. Structural elements are not damage tolerant, i. e. the crack growth time is extremely short.
2. The crack is "predetermined" by manufacture and grows slowly starting form the first flight.
3. The crack initiates in operation and grows relatively slowly.

The proposed method of prolonging the service life refers mainly to the second and third situations. As the basis for definition of the amount of the selective inspection the following model is assumed.

The crack growth process consists of two stages - crack initiation and propagation. The crack initiation stage covers the period until the crack reaches the length l_0. Assume to be the length of a crack, detectable at the specified probability P_0

The fatigue life distribution function (for the time at which the crack reaches the prescribed length), $P_l(N)$, is assumed log-normal. The life scatter is the same for all crack lengths. The time before the crack initiation, N_{l_0}, and the crack growth time, N_d, are independent. The time before the failure, N_c, is defined by the relation

$$N_c = N_{l_0} + N_d \qquad (6)$$

To provide the required safety the selective inspection should de done at the time N_K equal to the safe life period. The sample size n is determined in accordance with both the adopted model and the requirement to find at least one crack at the specified probability P_{det} where

$$P_{det} = 1-(1-P_{l_0}(N_K)\cdot P_0)^n \qquad (7)$$

whence

$$n = -\lg(1-P_{det})/\lg(1-P_{l_0}(N_K)\cdot P_0) \qquad (8)$$

where P_0 is the probability of crack detection at $l \geq l_0$ (P_0 is defined by the reliability of inspection method); $P_{l_0}(N_K)$ is the probability of the presence of the crack $l \geq l_0$ at the time N_K, and is to be found from the log-normal distribution law with the average $\bar N_{l_0}^{(k)}$.
If after the inspection of n elements no cracks are detected, this means that with the probability P_{det} the actual value of the average life $\bar N^{(k)}$ (until the crack length l_0 is $\bar N^{(k)} > \bar N_{l_0}^{(k)}$.
Therefore, the operational life can be prolonged by a certain portion of the corrected crack growth time ($(\bar N_d)/K$, K is the number of inspections during $\bar N_d$), divided by the safety factor η_d to allow for the crack growth time scatter: $\Delta N = (\bar N_d)/\eta_d \cdot K$.
If the reliability of the inspection method is high enough ($P_0 \geq 0.9$), then K value can be assumed to be 2.
Determine, for example, the selective inspection amount for the structural elements having the following properties:
- the average life before l_c, got in tests, is the same for any point: $\bar N_c$ = 120,000 flights;
- service life RMS deviation σ = 0.15;
- crack grows from l_0 to l_c for times of 0.1 $\bar N_c$, 0.3 $\bar N_c$, 0.5 $\bar N_c$, 0.7 $\bar N_c$;
- the total safety factor $\eta_\Sigma = \eta_1 \cdot \eta_2 \cdot \eta_3 \cdot \eta_4$= 4;
- the safe life N_z^{6} = 30,000 flights.

Under these conditions, we obtain $\eta_4^{(z)}$= 2.9, and the corrected average life is $\bar N_c^{(k)}$= 87,000 flights. The time to the inspections is N_K = 30,000 flights. The sample sizes at P_0 = 0.98 and P_{det} = 0.9 are presented in Table 1.

Table 1. The inspection sample size.

$\bar N_c$ flights	$\bar N^{(k)}$ flights	N_K flights	$\bar N_d/\bar N_c$	$\bar N_d$ flights	n	ΔN prolongation flights
120,000	87,000	30,000	0.1	8,700	869	1,500
120,000	87,000	30,000	0.3	26,100	116	4,500
120,000	87,000	30,000	0.5	43,500	16	7,500
120,000	87,000	30,000	0.7	60,900	2	10,500

One can see in Table 1 that the selective inspection is more effective at larger crack-growth times. The number of the inspected aircraft is affected by the number of the similar concentrators in the airframe.

The presented method is illustrated below by an example concerning with the possibility to prolong the operational life of two critical zones of AN-24 aircraft:
1) horizontal cap of the second spar lower boom,

2) the end hole for mounting the fitting of the sixth rib of the front panel of the center wing section

For the first location the equivalent repeating stress (one cycle is equivalent to one flight) and the maximum in flight stress level are 125 MPa and 236 MPa, respectively. For the second location the above-mentioned values are 74 MPa and 125 MPa. The analytical model for the first case is the strip with a hole with an insert, and the strip with a loaded hole for the second case.

The critical crack lengths for these locations are, respectively, equal to 8.8 mm and 3.7 mm (the crack size is measured from one hole edge for a symmetric, two-sided crack).

The analytical evaluation of the crack growth time from different values of ℓ_o and the necessary sample sizes are represented in Table 2.

The sample size is defined by the following input data:
- the average time to the critical crack, $\bar{N}_c$ = 120,000 flights;
- life scatter RMS σ = 0.15;
- crack growth time scatter RMS σ_d = 0.10 (Konovalov,1989);
- total safety factor η_Σ =3.6;
- safe life N_Σ^s = 33,330 flights;
- the probability of crack detection at $\ell \geq \ell_o$, P_o = 0.98;
- the required probability to detect at least one crack at the selective inspection, P_{det} = 0.9.

Table 2. The sample size for two zones of AN-24

zone	$\bar{N}_c$, flights	$\bar{N}_d$, flights	$\bar{N}_c^{(K)}$ flights	$N_K = N_\Sigma^B$ flights	n	ΔN, flights	notes
1	120,000	52,000	96,660	33,330	30	10,470	ℓ_o = 0.1mm
1	120,000	25,000	96,660	33,330	262	5,035	ℓ_o = 0.5mm
2	120,000	29,000	96,660	33,330	207	5,840	ℓ_o = 0.1mm
2	120,000	17,000	96,660	33,330	566	3,420	ℓ_o = 0.5mm

The above samples are for "isolated" concentrators. If we assume that there are about 100 locations of each of two types in one airplane, then the number of inspected aircraft is, respectively, 3 and 6 at ℓ_o = 0.5 mm. The final decision on the inspection is to be made on basis of the inspection feasibility.

REFERENCES

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