Schematization of loadings and errors arising thus in estimates of crack growth duration

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Abstract

The general block diagram of crack growth modeling and periodicity of aircraft elements controlling was worked out. The major factors determining the size of calculation inaccuracy $\varepsilon_N$, under calculations of the crack growth duration $N_*$ and the inspections intervals $t_0$ was marked and estimated with the help of the diagram.

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The Procedure of the fatigue life modeling and the control periodicity consists of three parts (Fig.1) \textsuperscript{[1]}. The first part includes the choice and the development of a loading model using in tests and calculations (unit 1 on the Fig.1). The ratio error $\varepsilon_L$ appears in this part. see Fig. 2.

The second part includes the development of the mathematic model of crack growth and the methods of its solution (units 2…13). In this case appear errors connected with inadequacy of model itself $\varepsilon_{K}$ (unit2), errors of parameters estimation $\varepsilon_{H}$, $\varepsilon_{C}$ (unit 8), inaccuracy in consideration of operation condition $\varepsilon_{d}$ (unit 9).

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1. Choice of operational loading model

Harmonic load
Standard eight-step unit
Typical flight
Determinate and quasi-random block-program
Tensometric notes
Random process

2. Choice of kinetics equation

\[ i = f^i(K, \bar{p}, \bar{q}) \]
\[ K = K_0^i \phi_1^i \phi_2^i \phi_3^i \phi_4^i \phi_5^i ; \]
\[ \bar{p} = (C, n, K_0, K_{th}, K_{fc}, ...) ; \]
\[ \bar{q} = (E, \sigma_0, \sigma_B, ...) . \]

3. Database on material and construction survivability

4. Experiment results

5. Maintenance data

6. Package of programs and calculations

7. Methods and means of nondestructive check

8. Concrete definition of equation

\[ f^i = f^o ; \]
\[ \bar{p} = \bar{p}^o ; \]
\[ \bar{q} = \bar{q}^o ; \]
\[ K_0^i = K_0^o ; \]
\[ \phi_1^i = \phi_2^o ; \]
\[ \phi_4^i = \phi_4^o ; \]
\[ \phi_2^i = \phi_4^o = \phi_3^o = 1 . \]

9. Construction feature

10. Estimation \( l_{pec}, l_{e} \)

11. Estimation \( l_{tot} \)

12. Accounting of maintenance condition

Multi-axis load
Corrosion
Ageing
\[ \phi_2^i = \phi_2^o ; \]
\[ \phi_4^i = \phi_4^o ; \]
\[ \phi_5^i = \phi_5^o . \]

13. Calculation of survivability period

\[ f^i = f^o ; \]
\[ \bar{p} = \bar{p}^o ; \]
\[ \bar{q} = \bar{q}^o ; \]
\[ K = K_{tot}^o \cdot \phi_1^o \cdot \phi_3^o \ldots \phi_5^o . \]

14. Calculation values of survivability characteristics

15. Results analysis

16. Determination of checkup periodicity

17. Modification of construction. Changing of operation condition

Fig. 1. The block diagram of the modeling of crack growth duration and control periodicity

The third part includes the development of procedure of estimation of periodic inspection of aircraft construction elements (unit 15-16). The definition of surely detected crack (with the 0.95 probability) \( l_{d} \) is used there (unit 11).

Generally listed above errors is difficult to estimate, however can be done some recommendations for the increasing of the calculation accuracy of fatigue life.

Let's divide this task. In the beginning it is necessary to estimate the error caused by replacement the real loading spectra of aircraft design and its model by block-program. Then it is necessary to define the error introduced by crack growth equation itself. However it is practically not possible to do it without tests data on cyclic crack resistance and aircraft design elements under loadings with variable amplitude. The methodical error brought by simulation of operational loading by the block program, mainly is defined by distribution of amplitudes and to a lesser extent an average of process and its standard deviation [2].
For the analysis of the error ($\varepsilon_L$) the experimental researches of fatigue crack growth under random Gauss processes and “block-program” loading was carried out. Fatigue tests realized on center cracked panels of 450x100 mm in the plan with 3 and 8mm in their thickness. Two Al-based alloys D16AT – the same as 2024-T3 and V95ATV – 7075T6 with different states of material compositions because of material cleaning during manufacture procedure were investigated. The results of these researches is in the [2…5]. The modeling of the random loading with “block-programs” formed by “rain-flow” method has acceptable precision of results ($\varepsilon_L \sim 5...30\%$). It was suggested for random cyclic loadings to introduce in tests only cycles with amplitudes bordered by criterion $M \pm 2S$ to exclude big scatter in test results and help their reproducing in unified manner ($M$ – average, $S$ – standard deviation).

In general it is not possible to evaluate the error of estimation of survivability characteristics caused by inaccuracy of definition of kinetic equation parameters ($C$ and $n$). Let’s do the estimation for simplest variant - center cracked panel loaded by cyclic stress with constant stress range $\Delta\sigma$. The range of stress intensity factor is $\Delta K = \Delta\sigma\sqrt{\pi l}$. For a crack growth model will be use the Paris-Erdogan equation. As $n$ is the degree parameter it is necessary to expect the error in fatigue life calculation. Let parameter $C$ be determined precisely, and instead of true value of parameter $n$ in calculations was used the $n_{\text{est}}$, parameter having an error $\varepsilon_n$.

For approximate orientation in errors sizes of $\varepsilon_{N_L}$ we will carry out concrete calculations. Let's consider as object the bottom panel of the IL-96-300 plane wing the around an integral tank. In this case the regulated (limit) crack length equal $l_{\text{reg}} = 250mm$. Assume that the crack can be found on a fuel leak. In this case reliably founded cracks have the length $l_d = 75mm$. Let’s accept the true value of degree parameter $n = 4$ that is
For settlement loadings we will accept zero-to-tension stress cyclic loading. For estimates of influence extent of cyclic loads level on an error the calculations we will carry out for two levels of loading $\Delta \sigma = 20\text{MPa}$ and $\Delta \sigma = 40\text{MPa}$. The calculation results in graphic form are shown on Fig.3.

![Fig. 3. The calculation results](image)

The error in an evaluations of parameter “n” have a big influence on the calculation results of fatigue life $N_*$, and therefore on the estimation results of control periodicity $\tau$. The error in fatigue life calculations much exceeds an initial error in parameter “n” estimates (single-order). From Fig.3 we can see that relative error 4% ($\varepsilon_n = -0.04, n_e = 4.16$) leads to error of fatigue life estimation $\varepsilon_{N_e} = 90\%$. The ratio error $\varepsilon_n$ in a determination of a degree parameter can increase on two orders the error $\varepsilon_{N_e}$ in the calculation of a fatigue life $N_e(\varepsilon_{N_e}\sim 10^{\cdots} 10^2 \varepsilon_n)$. From fig.3 you can see that identical errors on the module at definition of parameter “n” will not give identical errors on the module in fatigue life estimation. The curve in positive part of errors is the flat. The calculation loading levels practically don’t influence on fatigue life calculation results. The error $\varepsilon_{N_e}$ is limited by value 1.5. In the negative part of abscissa axis the errors values $\varepsilon_{N_e}$ achieve values of 8…13. Thus mistakes in the “smaller party” of $\varepsilon_n$ can lead the single-order increase of calculation of fatigue life. In practical point of view it is means that if it is impossible to determine precisely the parameter “n” it is better to be mistaken in the positive way ($\varepsilon_n > 0$). It will lead on extremely measure to the calculations in a stock and will limit the fatigue life calculations errors.

The error caused by inaccuracy of definition $l_{d\sigma}$ also doesn't depend on range stress $\Delta \sigma$. Therefore the error of fatigue life calculations is comparable with the initial error ($\varepsilon_{N_e} \sim \varepsilon_l$).

Errors $\varepsilon_\sigma$ of definition of range stress $\Delta \sigma$ is single-order than errors in definition of the fatigue life characteristics $\varepsilon_{N_*}$. 


References

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