# Development of the RRJ Airplane Wing Fatigue Test Spectra

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## Introduction

It is known, that correct selection of type and parameters of loading spectrum of fatigue test program of transport airplane wing has the major value for reliability of the results received during fatigue tests. Till 1980th years the majority of transport airplane wings has been fatigue tested with use so-called "block", enough the simplified programs of loading representing, as a rule, the block of loads for one typical flight with several stages of loading and constant amplitudes of program loading at each stage.

Introduction of computer facilities in practice of experiment has allowed to receive and realize in practice quasi-random loading programs which presenting now most complex and close to the operational conditions of loading programs of fatigue tests. Results of numerous experimental researches with use quasi-random programs have shown, that tests under such programs is the most reliable method of an experimental estimation of fatigue life of airframe elements, selection of a material and technology, obtaining of the information for creation and checks of new methods of fatigue analysis.

Since 1980th years Airbus and Boeing companies completely went on quasi-random type of loading spectrum of fatigue test programs of wings of transport airplanes. The Russian aircraft manufacturing firms are not so unified in selection of spectrum type of similar programs, some from them still choose "block" type of loading spectrum of fatigue test programs.

With the purpose of the substantiation of type selection of the Russian regional airplane (RRJ) wing fatigue test spectra comparison of main principles of development, merits and demerits "block" and quasi-random programs of fatigue tests of wings of transport airplanes is carried out.

## Merits and demerits "block" and quasi-random programs

To doubtless advantages of "block" programs of tests it is possible to attribute relative simplicity of a technique of development of such programs.

To demerits of "block" programs of tests it is possible to attribute the following:

- "Block" programs do not reflect many features of loading of a wing in operation (various amplitudes of loading, various repeatability of various amplitudes, various flight damageability, etc.), however is well-known, that the listed features render significant influence on fatigue durability of airframe elements;
- As a rule, by development of "block" programs levels of cutting off of the big and small loadings either are not determined at all, or determined formally, however also it is known, that extreme loads and loads of small amplitudes and the big repeatability bring the special contribution to accumulation of fatigue damageability of airframe elements; it is known also, that the account of this contribution with use of a hypothesis of linear summation of fatigue damages is far enough from results of experimental estimations;
- Wide use of a hypothesis of linear summation of fatigue damages can result to that for the same plane by various authors various "block" programs can be developed, however each program will have the damageability very frequently rather far from damageability at real operational loading;
- As consequence investigation of the demerits marked above, significant mistakes are as a result of tests;
- Significant mistakes are in fatigue life calculations at "block" program loading: calculations or on a hypothesis of linear summation, or on a hypothesis of “relative linear summation” with use of obviously inexact values of accumulated fatigue damages (as a rule, identical to all constructive concentrators of a wing and received also at "block" loading) cannot give results comprehensible on accuracy as do not take into account specificity and distinctions of values of accumulated fatigue damages for various wing elements.

Quasi-random programs differ from "block" first of all that formation of a program spectrum loading is actually based on transition from cumulative occurrences of incremental vertical load factor in CG of airplane to differential occurrences, validity of such transition does not cause doubts.

Advantages quasi-random programs of tests are:

- Programs of quasi-random loading full enough reflect the majority of features of loading of airframe in operation and, thus, are closest to real operational loading;
- By development of similar programs application of any hypotheses of summation of fatigue damages is not provided;
- As consequence investigation of the advantages marked above, is significant the big confidence of accuracy of experimental estimations.

Demerits of quasi-random programs are:

- Relative complexity of development and realization;
- Special requirements to validity of cumulative occurrences of incremental vertical load factor, which is a basis of quasi-random programs;
- Complexity of fatigue life calculations at quasi-random loading.

In the present work with the purpose of the further research of merits and demerits "block" and quasi-random programs the comparative estimation of the expected accumulated fatigue damages which can be received for typical constructive elements of wings of some transport airplanes at fatigue tests by "block" and quasi-random programs is carried out.

A number of researches on optimization of parameters quasi-random a spectrum of loading of the program of fatigue tests of RRJ airplane wing is carried out also.

## An estimation of values of the expected accumulated fatigue damages at fatigue tests of wings of transport airplanes

In works [1,2] for fatigue life analysis at quasi-random loading of elements of a wing of the transport airplane it is offered to use the special regression equation which application allows to increase accuracy of calculations considerably:

$$N_{fl}\sigma_m^m\overline{\sigma}_{eqv}^n = 10^{a+b\overline{\sigma}_{a\max}+c(1-R)}, \qquad (1)$$

where:

- $N_{fl}$ - fatigue life of an element (in flights);
- $\sigma_m$ - gross stress in the element at an operation load or mean stress in flight;
- $\overline{\sigma}_{a\max} = \sigma_{a\max}/\sigma_m$ - relative maximal amplitude stress of the quasi-random loading program block;
- $\overline{\sigma}_{eqv} = \sigma_{eqv}/\sigma_m$ - relative equivalent stress of average (on damage) flight of the quasi-random loading program block;
- $R = \sigma_{\min"GTAC"}/\sigma_m$ - relative minimal stress level of “ground to air” cycle of the quasi-random loading program block;
- *a, b, c, m, n* - the constants of equation (1), dependent on constructive - technological features of an element, type quasi-random loading spectrum, and determined on a basis regression analysis of the empirical data.

In work [2] the conclusion about a basic opportunity of use of the equation (1) with constants *a, b, c, m, n*, corresponding to the certain sample or a constructive element and the certain type of quasi-random loading spectrum, for fatigue life analysis of the same samples or constructive elements of wings of transport airplanes at the other type of quasi-random loading spectrum or at "block" program of loading is made.

In work [1] on the basis of the equation (1) expression for an estimation of values $\overline{A}$ of the expected accumulated fatigue damages for various constructive elements of wings of transport airplanes at quasi-random loading such wings is received:

$$\overline{A} = 10^{(a-c_0)+b\overline{\sigma}_{a\max}+c(1-R)} \times \sigma_{экв}^{m_0} \times \sigma_m^{-m} \times \overline{\sigma}_{экв}^{-n} . (2)$$

The equation (2) represents regression function installing dependence of magnitude $\overline{A}$ from four most important parameters of qusi-random spectra ($\sigma_m$, $\overline{\sigma}_{a\ max}$, $\overline{\sigma}_{eqv}$ and *R*) and including seven constants (*a, b, $c_0$, c, $m_0$, m, n*), describing a fatigue resistance of a considered structural element at regular (pulse) and irregular (quasi-random) loading depending on a material and structurally - technological singularities of the element. These constants are determined on the basis of the regression analysis of empirical data. Actually it is possible to state, that the function (2) installs connection between fatigue performances of the considered element at regular and irregular loading.

The equation (2) allows at known values of constants *a, b, $c_0$, c, $m_0$, m, n* for any sample or a constructive element of a wing of the transport airplane and known values of "key" parameters $\sigma_m$, $\overline{\sigma}_{a\ max}$, $\overline{\sigma}_{eqv}$ and *R* any quasi-random loading spectrum to determine value $\overline{A}$ of expected accumulated fatigue damages of this sample or a constructive element.

In work [2] the basic opportunity of use of a equation (2) with constants *a, b, c, m, n*, corresponding to the certain sample or a constructive element and the certain type at quasi-random loading, for an estimation of values $\overline{A}$ for the same sample or constructive element at the other type of quasi-random loading or "block" program loading is shown also.

In the present work a comparative estimation of values $\overline{A}$ which can be received for typical constructive elements of the lower surface of wings of transport airplanes Ил-86, Ил-96-300, Ту-204, RRJ at fatigue tests with use various "block" and quasi-random loading programs is carried out.

The estimation is carried out for:

- typical element of wing lower surface - open holes, $\alpha_\sigma$=2.6, Д16чТ alloy;
- typical element of wing lower surface - strap joints, Д16чТ alloy.

Values of constants *a, b, c, m, n, $c_0$ , $m_0$* of the equations (1) and (2) for this elements are given at table 1 and 2 [1,2].

Table 1

*Values of constants a, b, c, m, n of the equations (1) and (2)*

| ## | Type of element | Type of spectrum | $\sigma_m$, Mpa | *a* | *b* | *c* | *m* | *n* |
|---|---|---|---|---|---|---|---|---|
| 1 | Wing lower surface - open holes, $\alpha_\sigma$=2.6, Д16чТ alloy | "TWIST", "MiniTWIST" | 96-144 | 19.2805 | 0.12 | -0.89 | 5.95 | 3.19 |
| 2 | Wing lower surface - strap joints, Д16чТ alloy | "TWIST", "MiniTWIST" | 75-100 | 15.1073 | 0.75 | 0.16 | 3.25 | 13.8 |

Table 2

*Values of constants $c_0$ , $m_0$ of the equation (2)*

| ## | Type of element | Type of loading | $c_0$ | $m_0$ |
|---|---|---|---|---|
| 1 | Wing lower surface - open holes, $\alpha_\sigma$=2.6, Д16чТ alloy | Pulse cycle | 15.4053 | 4.56 |
| 2 | Wing lower surface - strap joints, Д16чТ alloy | Pulse cycle | 13.7044 | 4.00 |

Table 3

*RRJ quasi-random fatigue loading program.*
*Definition of flight types and number of load cycles within each flight*

| Flight type | Number of flights in one block of 5000 fls | 5 amplitude levels ($\sigma_a$ / $\sigma_m$) | | | | | Total number of cycles per flight |
|---|---|---|---|---|---|---|---|
| | | I 1.10 | II 0.92 | III 0.68 | IV 0.41 | V 0.19 | |
| | | Number of gust loads (full cycles) | | | | | |
| A | 1 | 1 | 0 | 11 | 120 | 258 | 390 |
| B | 6 | | 1 | 1 | 65 | 118 | 185 |
| C | 56 | | | 1 | 33 | 61 | 95 |
| D | 1193 | | | | 1 | 29 | 30 |
| E | 3744 | | | | | 20 | 20 |
| Total number of cycles per block of 5000 flights | | 1 | 6 | 73 | 3551 | 113859 | |
| Cumulative number of cycles per block of 5000 flights | | 1 | 7 | 80 | 3631 | 117490 | |

RRJ quasi-random loading program block is given at table 3. RRJ "block" loading program is given at fig. 1. Quasi-random loading programs and "block" loading programs for Ил-86, Ил-96-300, Ту-204 are not given with the purpose of reduction of volume of present article.

Estimation of values $\overline{A}$ for open holes is given at fig. 2, estimation of values $\overline{A}$ for strap joints is given at fig. 3.

Despite of the certain reserve of the lead estimations of values $\overline{A}$ with use of a equation (2), it is possible to assert, that there is a significant difference of values $\overline{A}$ of "block" and quasi-random loading.

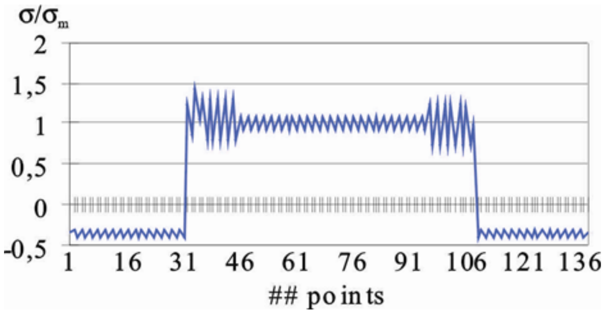


Fig. 1

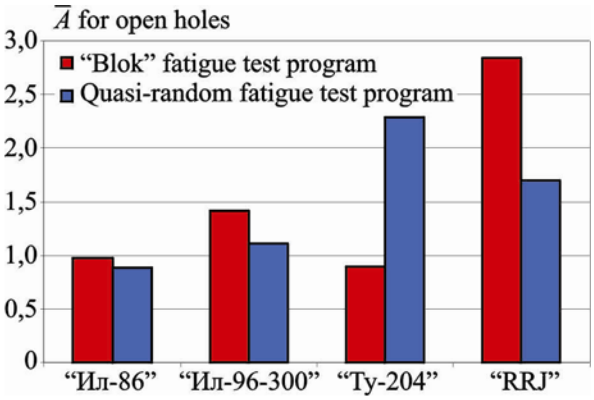


Fig. 2

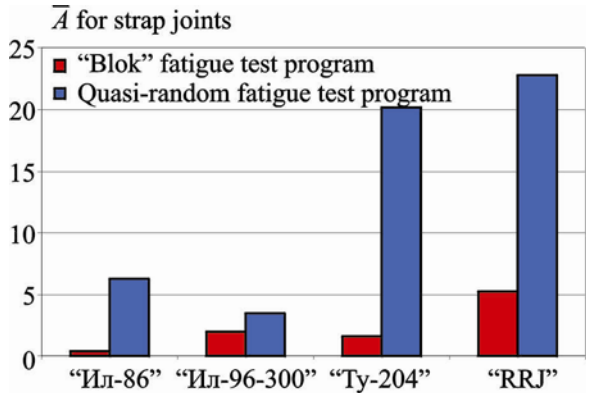


Fig. 3

Taking into account sufficient affinity of parameters of quasi-random program loading and parameters of operational loading, it is possible to assert also, that there should be a difference of the same order in values of values $\overline{A}$ of "block" program and operational loading. This fact ***in addition*** confirms expediency of use of quasi-random program loading for an experimental estimation of fatigue life of wings of transport airplanes and practical inexpediency of use for this purpose of "block" program loading.

## Comparison of damages of RRJ various quasi-random loading spectrum types

A number of researches on optimization of parameters of RRJ wing fatigue test quasi-random loading spectrum is carried out with use of the equation (1). With this purpose comparison of damage of various types quasi-random spectra of loading which can be developed for a wing of this airplane is carried out – look fig.4, where:

$$K = N_{cont.sp.} / N_{sp.},$$

where:

- $N_{cont.\ sp.}$ - fatigue life of an element (in flights), calculated with use of the equation (1) at loading of continuous spectrum;
- $N_{sp.}$ - fatigue life of the same element (in flights), calculated with use of the equation (1) at loading of "10x10", "5x5" or "5x5 with correction of amplitudes" types of spectrum.

Practical necessity of updating of separate parameters of loading of a spectrum such as "5x5" (quasi-random a spectrum for full-scale fatigue tests of a wing of airplane RRJ) for maintenance of damageability, close to of accumulation of damageability of the "10x10" spectrum (a reference theoretical spectrum of loading of a wing of this airplane) or continuous spectrum is shown at fig. 4.

It is obvious, that it can be achieved with use of correction of amplitudes of a spectrum "5x5". On figs 4 it is shown, that the spectrum "5x5 with correction of amplitudes " has the damage equal to damage of a continuous spectrum.

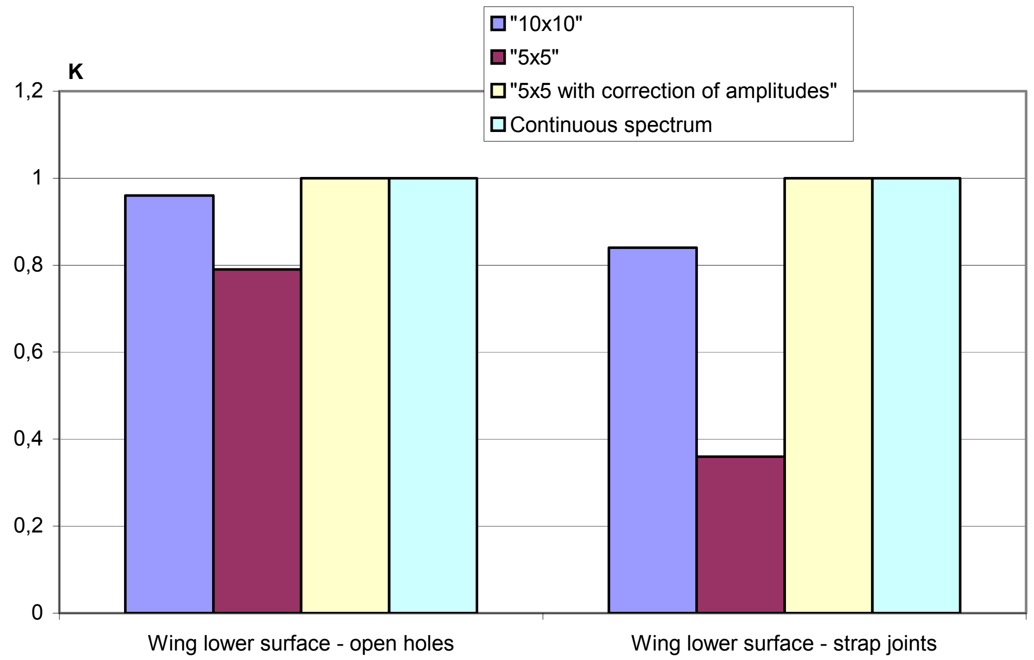


Fig. 4

## Conclusions

1. With the purpose of the substantiation of type selection of the Russian regional airplane (RRJ) wing fatigue test spectra comparison of main principles of development, merits and demerits "block" and quasi-random programs of fatigue tests of wings of transport airplanes is carried out. It is marked, that the main advantage quasi-random programs of tests is that frequency and value of loads of quasi-random spectrum get out without use of any models of accumulation of damageability.
2. Full-scale fatigue tests with use quasi-random loading programs it is necessary to recognize the most reliable method of an experimental estimation of fatigue life of wings of transport airplanes. Use for this purpose of "block" loading programs is practically inexpedient and can result in serious mistakes.
3. Practical necessity of updating of separate parameters of loading of a spectrum such as "5x5" (quasi-random a spectrum for full-scale fatigue tests of RRJ airplane wing) for maintenance of damageability, close to damageability of the “10x10” spectrum or continuous spectrum is shown.
4. It can be achieved with use of correction of amplitudes of a spectrum "5x5".

## References

[1] Strizhius V. Fatigue life equation at quasi-random loading of the longitudinal elements of transport airplane wing. *TsAGI Scientists Notes,* T. XXIX, No. 3-4, pp 144-152,1998.

[2] Strizhius V. Calculation of fatigue life of transport airplane wing elements at complex program loading. *TsAGI Scientists Notes,* T. XXXIV, No. 1-2, pp 115-122,2003.