ON EQUIVALENCE OF POLYMER COMPOSITE MATERIALS STRUCTURES LOADING PROGRAMS UNDER FULL-SCALED SERVICE CYCLE TESTING

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Keywords: *equivalents, service life, composite materials, tests, service loading*

Abstract

The CFRP application to manufacture the highly loaded critical aircraft structures components such as the wing made it necessary to verify the possibilities to use the approaches that existed previously to develop the loading programs for full-scale service life tests, which are required to proof the structural integrity in the certification. The main procedures and approaches are given, which are recommended by the RF Airworthiness authorities to provide the equivalency of transport airplanes metal-composite structures loading under certification tests to service loading condition. Procedures and approaches are developed based on analysis of international and national experience in area of polymer composite aircraft structures creation.

Introduction

The appearance of composite-metal structures has raised the actuality to modify the structure loading programs procedures and approaches at full-scale service life testing. Currently, these procedures for metal structures are perfected quite well and verified by operational experience. The main conclusion, which is possible to be made, when analyzing these methods, is to take in a mandatory account the principle features of material and structural components fatigue damage mechanisms. At this, the CFRP destruction physics differs greatly from that one of metal structures.

In spite of the CFRP structures advantages the CFRP structures certification is not developed enough. This is due to insufficient experience in creating the large-dimensional structures, the more complicated and various fracture mechanisms, the CFRP structures sensitivity against the service factors (moisture, temperature and so on), as well as the higher scattering features vs. the metal structures, what is especially typical for the fatigue characteristics.

The paper gives the basic principles and approaches, which are used currently to provide the aircraft composite-metal structures full-scale testing equivalency to standard exploitation conditions. The principles and approaches are developed based on the analysis of practical creation and certification of a number of national and foreign aircraft CFRP structures. At this, the application of test results for certification is assumed to be the main purpose of such tests therefore the latter are required as follows:

- All most known features of fracture processes in metal structures and CFRP ones are to be taken into account;
- Impossibility to obtain the non-conservative results;
- Acceptable time to obtain the data needed, as well as the higher cost-saving efficiency of service life validation procedure.

The transport aircraft are highlighted, which of the certification is being performed in conformity with AP-25 [1]. It is to be noted that the approaches under development are possible to be used after some modifications for another types of aircrafts.

1 Equivalence of Variable Loading at Full-Scale Tests vs. Standard Operation

When estimating the aircraft structures service life characteristics, beyond other issues, in conformity with MOC 25.571 [2], the principal structural elements equivalents are to be found out between the operational loading spectrum and the program one, which is used under full-scale tests. The operational loading spectrum is generated based on the unit operational loading spectrum analysis, which represents the standard per-flight variation of the functioning loading and the integral iteration of random variable loads of different levels. At this all the loading significant components and the phase correlations are to be taken into consideration, as well as the structural dynamical features. Usually, the operational spectrum is generated based on the data of airplane operational loading (airplane-analog, test specimen, flying laboratory, and so on) and/or on the computational results of dynamically-scaled structure model. The spectrum has a great number of cycles with various parameters. The time duration of direct work-off of such loads test sequence is comparable with that one of structure operation time. Therefore, the sequence is simplified by principles, which are developed for metal structures and which are given in [3, 4, 5, 6]; and the simplified loading program generated for full-scale tests (PFST).

At full-scale service life tests of airframe, it is hardly possible to reproduce the entire scope of external loads, which correspond to the real operation. It is conditioned by the fact that under the tests vs. the standard flight [7]:

- the test object masses distribution differs from that one of aircraft due to substitution of standard units by their models (engines, landing gear, stabilizer, fin, flaps, and slats), as well as absence of fuel, pay load, equipment, and so on;
- the distributed aerodynamic loads are reproduced by concentrated efforts;
- variable loads dynamic distribution is replaced by distributions that correspond to static loading cases;
- phasing of in-flight loads on different aircraft units differs from that one on tested object units under full scale tests;
- when testing the composite-metal structures, the test loads are increased (enhancement) as compared with the typical operation loads.

Moreover, during testing when the fatigue damages are found out or when PFST is refined, the variable loads distribution is changed as compared with the original distribution.

Thus, the problem to define the equivalency arises in order to find out the correspondence between:

- PFST and operational loading spectrum;
- Different parts of PFST;
- Life characteristics of structural components manufactured from different type materials.

The last problem has recently become hot due to active introduction of CFRP structures into principal structural elements.

The parameter been called an "equivalent" *Eq* is an equivalence unit of correlation between the operational loading and PFST, the meaning which of is a ratio of fatigues for a typical structure concentrator and which are obtained under loading by two programs under consideration:

$$Eq = \frac{N_{test}}{N_{serv.}}, \qquad (1)$$

where $N_{serv.}$ and N_{test} – are fatigues under loading by the operational spectrum and the PFST correspondently. Estimation of $N_{serv.}$ and N_{test} fatigues is carried out ether by the experiment based on results of elementary specimens testing or by the calculation at presence of reliable methods.

2 Specifics to identify the "equivalents" for metal and CFRP structures

Almost a century-old experience to develop aircraft metal structure demonstrated that the concentrator in form of an open hole [8] is most dangerous for structures. Therefore, as a rule, the "equivalents" are found out by use of elementary specimens in shape of a flat plate with an open hole. Moreover, the analogous data, but in a limited amount, are obtained for typical joints specimens.

For CFRP structural components there exists no a generally accepted procedure to find out the loading programs equivalency due to CFRP structures specifics:

- Insufficient state of knowledge of such structures, including the lack of currently reliable experience of using the fleet of transport aircraft with such highly loaded critical components as wing or fuselage. This is because the final verification of designed methodology and design principles validity is possible only after the accomplishment and analysis of exploiting the rather representative structures fleet.
- The presence, especially in layered CFRP, which are used currently, of a great number of multiple modes of fracture, which are characteristic for various concentrators in structures. It leads to the necessity to provide for in Building Block [9, 10] research program the definition of the strength and correspondently of the "equivalents" for various types concentrators as the comprehensive data on their threat are lacking. Moreover, the fracture mode may change not only as a result of loading level change, but even under its direction change. That is why, if for fracture modes which are characterized by CFRP reinforcement fracture (tension, compression) the concentrator in form of hole remains mainly the most dangerous, then for modes, which are characterized by the matrix strength (shear, delamination) this is not so evident.
- The dependence of CFRP strength characteristics on a great number of various factors, including the manufacturing technology. At this, the materials that have formally the same structure, composition, and ingredients, but manufactured by different technologies or even at different enterprises, may demonstrate quite different life characteristics, which may be described by different relations. This, when introducing a novel CFRP, leads to necessity to perform a comprehensive and costly research cycle to verify the structural material properties homogeneity, as well as to find out all the CFRP properties, which are responsible for structure life characteristics and to verify the applicability of the basic relations and principles that are used when calculating the fatigue (e.g. the fatigue damage accumulation model, S-N diagram, constant life diagram, etc.). It means that the experience been accumulated when introducing one type of CFRP is impossible to be used for another material without additional experimental verification.

The main reason, why the evaluation of "equivalents" in conformity with (1) relation is practically impossible to be carried out experimentally for CFRP, is the specificity of modern CFRP fatigue behavior which is expressed by the high slope of S-N diagram. At this the major contribution in fatigue is made by maximal single loading cycles only; and the direct evaluation of the "equivalent" as a ratio of fatigues of two irregular loading programs requires the inadmissibly long time. Let it be shown by the explanation as follows.

In the research [11] the experimental data processing was performed for the specimen in form of a plate with open hole under irregular loading. The test results are taken from [12]. The Transport WIng Standard Test (TWIST) standard loading package was used for tests. Following the data in Table 1 [11] the greater part of flight block damage (about 60%) is formed by one maximal cycle, and two first loading steps, which consist of three cycles, contribute more than 90% of the total block damage. At this, six lower loading steps, which represent 398 639 block cycles from 398 665 ones contribute less than 1% of damage and may be excluded from loading program without loss of accuracy. To avoid the non-linear effects, all applied block cycles are to have fatigue more than 5000 cycles, i.e. the loading level when evaluating the "equivalents" for the TWIST block is to be chosen in such a way that the fatigue would be more than 5000/26 = 190 of such blocks, at this the total number of cycles will be more than $7.7{\cdot}10^7$, and the non-stop testing of one specimen under 5Hz frequency is about a half-a-year.

Such a limitation as an inadmissibility for the loading cycles with fatigue less than 5000 to be in program is based on the experience both to test other materials types (as a rule, the S-N diagram linear section is in range of $5{\cdot}10^3 \div 10^6$ cycles) and to investigate the CFRP under irregular loading, what has been carried out at TsAGI. In particular, when inv estigating the CFRP it was demonstrated that at presence in loading program of cycles with fatigue less than 5000 the total of fatigue damages when using the linear damage accumulation model the sum of damages is in range of 0.1 ÷ 0.5, and the exclusion of such cycles results into range of 0.65 ÷ 1.1, i.e. the linear accumulation model is valid for the last case.

One of the main reasons for the non-linear effect to present is that for the CFRP, as well as for the major part of other materials, the fatigue curve is of S-shape, which allows the linear approximation in logarithmic axes for the central zone only (see Fig.1). The blue line denotes the S-N diagram that is plotted based on experimental values within the entire fatigues range ("Test"); the red line denotes the experimental data approximation by linear dependence, which crosses the static strength point ("Linear approximation"), and the green line denotes the linear approximation in range of $5{\cdot}10^3 \div 10^6$ cycles ("Designed curve ").

Following the Fig.1 it is clear that, when using the "Designed curve" in range of 5000 cycles, the fatigue values will be obtained, which are overestimated in relation to real ones. It will lead, correspondently, to decrease in fatigue damage sum calculated by the linear damage accumulation model. Similarly, for the lower fatigue curve knee, the consideration of cycles with fatigue more than 10^6 leads to fatigue damage sum overestimation.

The complexity to plot the CFRP S-N diagram is determined by high slope of diagram and large scattering of experimental data. So, the more experimental points (as a rule, more than 15) are required to plot correctly the diagram vs. the metal alloys one. The discussion on method to plot the S-N diagram is connected with these complexities, including; and, in particular, if it is worthy considering at this the static fatigue points. Under insufficient amount of data, especially when unsuitable selection of testing facilities basis, one sometimes obtains the "cloud" of experimental values, which are practically impossible to be approximated reasonably. In this case, the use of static strength points makes it possible to carry out the correct estimation of S-N diagram parameters under condition that the experimental points under cyclic loading are located on bases in range of $5{\cdot}10^5 \div 10^6$ cycles, as the use of points with less fatigue may lead to extra optimistic values. As an example (Fig.1) the "Linear approximation" curve is given, which crosses the static strength point and the S-N diagram lower knee point. It shows that such a curve makes it possible to obtain the fatigue values as conservative results in the entire range of values. All the curves located above have the limited areas of application.

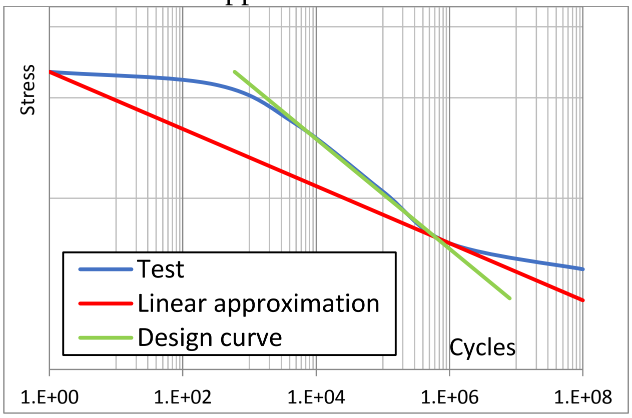

Fig. 1. S-N diagram and its linear approximations

3 Standard full scale life tests program for composite-metal part

The specifics mentioned above create complexities when introducing the CFRP into manufacturing the critically important highly loaded structural components. These complexities in conformity with the regulation in effect currently [2, 9] are overcome by use of approaches as follows:

- Non-growth damage approach. According to it one must show that the Category 1 defects [2], which are in the most loaded areas do not increase in size and do not drop the structural strength below the ultimate level value. Moreover, in some cases after operation is expired, the damages may have sizes, which do not surpass the maximally allowable manufacturing defect level (Category 1) that meets the approach of no-detrimental damages growth. Logic of the latter one consists in fact that the presence of defect of Category 1 in any case must not lead to reducing the stress below the ultimate level. At this it is to be considered all the scope of requirements to allowable manufacturing defects, including sizes and distances to other defects or structural irregularities.
- "equal reliability" approach, accordingly to which the CFRP structure is to demonstrate that its life characteristics are not worse than the analogue metal structure has, which is designed accordingly to existing proven methods. Taking into account that the current aircraft CFRP structure in major cases contains metal components, i.e. it is composite-metal, this principle may be paraphrased as follows: the life characteristics of CFRP part of structure are to be not worse than of its metal one.

When using the "non-growth damage" and "equal reliability" approaches for full-scale life tests of composite-metal part or structure as a whole currently the actions sequence is used as follows:

1. Two identical full-scale batch-produced structures are tested: the first one is to proof the metal components strength and another structure is to proof the strength of composite components.
2. The loading program spectrum is under generation for full-scale tests by use of known principles and procedures, been accepted currently for metal structures.
3. To proof the metal components life characteristics by conventional metal structures program using the PFST, the full scale life tests are carried out of the first structure under certification. The test program is to be agreed with Airworthiness Authorities in order to lower the design risks and to assure that the structure experimental development scope is acceptable for the Certification Agency. The testing duration is usually equal to 2 ÷ 3 design service lives. After the life tests are accomplished in order to find out the residual strength, the structure with regulated damages [2] is tested under loading up to the limit level or its fracture. These test, as a rule, are performed within full scale life tests of airframe, and do not take into consideration the composite components.
4. To proof the CFRP components life characteristics the full scale tests of the second structure are also carried out by the program, which is agreed with Airworthiness Authorities, and use the PFST adopted for metal components, and with Category1 damages [2], but the loading is carried out with k^{σ}_{enh} additional load enhancement factor. This factor is introduced to take into account the discrepancies between the strength features scattering of metal and CFRP structures and to consider the climatic and operational factors effects on CFRP. Its value is usually equal to 1.15 ÷ 1.2 for current structures. The testing duration (or k^{N}_{enh} fatigue enhancing factor) is usually equal to 1 ÷ 3 design service lives. The enhancing factors assignment procedure is given in Section 5. After the life tests are accomplished in order to verify the non-growth damage approach it is to verify that the structural integrity is not worse than the ultimate level.
5. The fatigue damages and fractures of metal structural components, which are possible in course of tests by § 4, are not critical, and the structure tests may be continued after the replacement of such components. But these data based on the results of a special analysis may be taken into account when estimating the structure metal part fatigue characteristics with considering the equivalents between the

programs of loading the structure metal part under tests by §§ 3 and 4.

In some cases, due to application of special methods to form loading spectra, the combination of valid certified tests of metal and composite parts of a design is essentially possible, compensating raised dispersion of fatigue of a composite part of a design in relation to metal, great value of a slope of fatigue curve of CFRP. However, such approach is practically not used in world practice and the considerable amount of preliminary studies and the special analysis is necessary for proof of a possibility of his realization.

Another approach to test the only structure by step loading: at first to proof the metal part strength without k^{σ}_{enh} and then to load the CFRP part with enhancement factor was proposed in [13]. However, this approach implies the accomplishment of the total test cycle of the metal part. As a rule, this cycle for a transport aircraft is 3 ÷ 6 years, and the CFRP part tests are to be started before the authorization to exploit the aircraft commercially. So, such an approach may be used only for small airplanes (FAR-23) where the life tests cycle is not so long.

4 Specifics to generate the fatigue tests program loading spectra for CFRP part of composite-metal part

There are two approaches, when generating the PFST to test the composite structural part:

- To use the PFST developed tor the metal structure while multiplying its value by k^{σ}_{enh} enhancement factor and adapting the spectrum obtained in order to take in account the CFRP behavior specifies and tests environment;
- To generate the special quasi-random loading spectrum. To enhance the CFRP components fatigue tests results reliability, a number of requirements exist for such a loading spectrum, which distinguish essentially from those, which are used when developing the loading programs and spectra for metal airframe assemblies.

Taking into account, that currently there exists no the second approach, let's pay out attention to description of the first one only. The procedure itself to generate the quasi-random fatigue tests program flight blocks for aircraft composite-metal parts does not differs practically from the corresponding one for metal parts, but when generating it the composite structures specifics are to be taken into account in conformity with requirements and recommendations as follows:

1. When forming the program spectra, a special attention is to be paid to compressing loads reproduction adequacy.
2. The level of "low" loads been excluded out of operational spectra of loading while forming the program spectra may be much higher than the corresponding level for aircraft structures metal parts. The relevance to exclude the "low" loads out of operational spectrum of this or that level must be justified and verified by specimens tests.
   Due to the exclusion of number of "low" loads the flight blocks for composite units may seem somewhat simplified vs. the flight blocks for metal ones; that means to have less number of flight types, amplitude levels and so on. In particular cases, the flight may be represented by several GAG cycles only.
   The exclusion of the "low" loads out of spectrum is to be carried out before the scaling, at this the total spectrum damage is not to be decreased.
3. The "high" loads are to be represented in program spectrum in total amount with repeatability that corresponds to the assumed operational period repeatability (design service life, as minimum). The "high" loads (both under the tension and the compression) "cutoff" of any type is not carried out.
   The application of enhancement factor to spectrum" high" loads needs a certain caution and complementary researches. This increase must not result into loads growth over the maximal operational ones and cause the premature fracture of metal components as well as their above-standard plastic deformations. At this, to replace one cycle by several less ones the latter are not to follow one after another directly.

4. When generating the PFST with the purpose to provide its equivalency to the operational spectrum, as well as to the total cycle number optimization and correspondently, to the testing duration, the various re-forms of original operational loading spectrum may be used (e.g. to combine a number of low amplitude cycles into one high amplitude cycle; to combine a number of flight types under averaging the various functional loads, and so on).
   The equivalency of such re-forms which are conventional for the metal structures, but not approved sufficiently for the composite-metal ones, must be proofed by specimens' tests results.
   The equivalency of re-forms is found out at the level of plane stresses state reproduction (by each of loads components considering their reciprocal effect).
   It is to be noted that the number of program cycles is defined by the optimal of tests duration (by current concept, not more than 50 cycles per flight).
5. The stress ratio effect on fatigue is to be analyzed and considered. It is necessary to maintain within program the stress ratio, which are typical for all loading factors and which contribute mainly into damage.
6. The loading spectrum is to provide the tested structural components failure modes, which are correlated with that operational ones. The justification of loading program acceptability for certification tests must include the proof of experimental data for all failure modes, which are possible under operation.

5 "Equivalents" concept for CFRP structures

Considering the impossibility to find out directly the CFRP equivalent for different loading programs, as it is shown in Sec.2, the CFRP components equivalents problem is reduced the tests equivalency justification. At this, in accordance with the "equal reliability" principle the aircraft designer is to verify that the composite structure life is not worse than that of metal:

$$T_{CFRP} = \frac{N_{CFRP}}{\eta_{\Sigma CFRP} Eq_{CFRP}} > T_{met}, \qquad (2)$$

where T_{CFRP} – is a composite structural part life, which is verified experimentally;
T_{met} – is a metal structural part life, which is verified experimentally and possible to be taken as equal to aircraft designed one;
N_{CFRP} – is a mean time before failure of composite structural part;
$\eta_{\Sigma CFRP}$ – total safety factor of [2] composite structural part;
Eq_{CFRP} – is a composite structural part equivalent by (1), found out by calculation.

The methodology for structural analysis of Eq_{CFRP} must be thoroughly verified experimentally to assure that its application makes it possible to obtain conservative values. The last task is not unfeasible for CFRPs as due to S-N curve high exponent value, the high strength margins are appropriate for them. To illustrate the latter position, the S-N diagrams are given (Fig.2) for CFRP and metal structural components as well as the level of limit load. When plotting the S-N diagrams, the equal static strength of CFRP and metal structural parts was assumed, what is to be met for correctly designed composite-metal structure, moreover the CFRP S-N diagram exponent is chosen as equal to 20, what is a typical value for reinforcement failure modes.

Based on data (Fig.2.) it is clear that within fatigue being more than $5{\cdot}10^5$ the CFRP S-N diagram is significantly higher than the operational loading level. Therefore, even if consider the higher scattering of CFRP fatigue features, it is always possible to select for it the S-N diagram more left of experimental points and justify by it the conservatism of analysis method used. At this for a particular CFRP it is additionally necessary to verify the correctness of the fatigue analysis method under irregular loading and S-N diagram shape.

Being aware of Eq_{CFRP}, T_{met} and $\eta_{\Sigma CFRP}$ values it is possible to find out the N_{CFRP} (2), which is to be obtained under full scale tests to verify the required life. Considering that the value exceeds usually the analogue ones for metal components, the tests been enhanced by fatigue only (with $k_{enh}^{N} \geq \eta_{\Sigma CFRP}$) are practically impossible due to the significant duration of such tests. Therefore, the k_{enh}^{N} factor is given as equal (e.g. to test duration of the metal structural part) to 2 ÷ 3 designed lives, and the factor value is calculated considering the inequality as follows:

$$k_{enh}^{N}\left(k_{enh}^{\sigma}\right)^{m} \geq \eta_{\Sigma CFRP}. \qquad (3)$$

Based on results of national expert estimations and foreign issues, the paper [2] recommends to apply the factors values as follows: k_{enh}^{σ} = 1.15 and k_{enh}^{N} = 3; and these values may be used to generate the full scale structures test program before finalizing the building block of tests which substantiate their sufficiency.

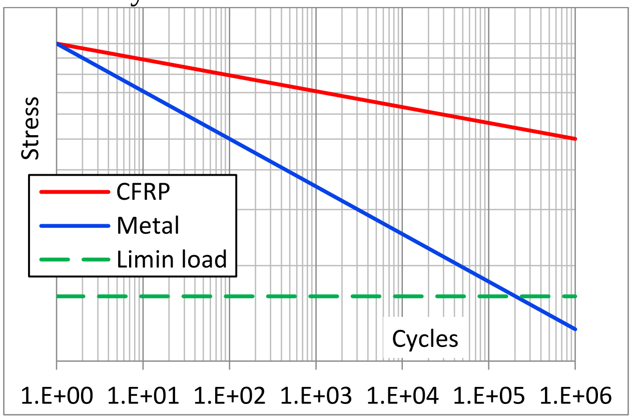

Fig. 2. CFRP vs. metal S-N curves

Moreover, within the Building Block it is to be demonstrated that the selected k_{enh}^{σ} and k_{enh}^{N} values satisfy the inequation (3) for any of possible modes for all stress concentrators, which define the structural strength. It is due to the fact that the $\eta_{\Sigma CFRP}$ and m values for CFRP may distinguish significantly for different concentrators. Correspondently, for concentrators fracture modes, for which the condition (3) is not met, it is necessary to develop the additional research program, usually using the structurally similar specimens with higher k_{enh}^{σ} and k_{enh}^{N} values. Based on the experience available such a program is to be carried out for concentrators in form of mechanical joints of various types, which have a higher fatigue scattering.

To verify the execution of inequality (3) for each fracture mode of each typical concentrator (structural irregularity & damage of the structure) it is to define the parameters as follows:

- $S_{\lg N}$ – standard deviations of fatigue of the structure. In some cases it is admissible instead of for structure to use for specimens of different levels (primary and structural similar specimens, panels, and joins), at this the results obtained at more complicated specimens are considered as the most representative ones;
- m – slope of S-N diagram for loading type (compression, tension, and shear) to which the fracture mode considered corresponds to concentrator under study;
- fatigue strength reduction factors due to operational actions to estimate the reliability factors. They are to be obtained based on fatigue tests results under various climatic conditions (moisture, temperature, technological liquids, ultraviolet, and so on). The factor value is admissible to be taken as an equal one to static strength reduction factors, but in major cases this may lead to extra-normative strength.

As a rule, all these parameters are estimated based on analysis of all results, obtained in the Building Block research. After all components are determined the inequality (3) in correspondence with [2] will be as follows:

$$S_{\lg N} \leq A\lg\left(\frac{\left(k_{фор}^{\sigma}\right)^{m}\cdot k_{фор}^{N}}{\eta_1\eta_2\eta_3\eta_4^{Норм}(n)\eta_5}\right)+0.15 \qquad (3)$$

$$A=\frac{1}{\left(3.09+\frac{1.28}{\sqrt{n}}\right)}.$$

where n – is a quantity of identical structural specimens, which are used to determine the structural fatigue;

$\eta_1\eta_2\eta_3\eta_4^{Норм}(n)\eta_5$ – are fatigue safety factors as correspondently to [2].

The relations (3) and (4) were obtained while using the items as follows:

- the S-N curve follows to power relation;
- the fatigue follows to lognormal distribution;
- the probability of structural non-destruction is assumed to be equal to 0.999 at reliability level of 0.9.

If based on research results, the departure from the mentioned aspects will be demonstrated, then, e.g. the S-N curve will not be able to be approximated by power law. It is necessary to develop a new procedure and program to proof the structure life characteristics, including the procedure to assign the safety factors, which are to be agreed with Aviation Authorities.

In summary it is to be pointed out that though the foreign regulations [14] are based on another provisions (Weibull distribution law for fatigue probability and B-basis (non-destruction probability of 0.9 at reliability level of 0.95), the analysis demonstrated that, in result, the foreign reliability factors for current materials are in a good agreement with the national ones.

6 Delamination

All the said above is about the strength and equivalency of CFRP components relates only to reinforcement fracture modes, i.e. to modes, under which the fracture takes place when the fibers strength is exhausted, but not when matrix or interface are destroyed. This due to the fact that the creation of structure, the material which of under operational force actions is destroyed by reinforcement, at least within the design life is one of the basic principles to design CFRP components. The relatively low interlayered strength of modern CFRP, which under corresponding conditions results into initiation of interlayered damages – delamination, is one of the factors, which hamper the creation of such structures.

The relatively low polymeric matrix strength as compared with that one of the carbon fiber is one of the basic reasons for delamination to appear. Over the recent half-century, the carbon fiber strength has considerably enhanced while the matrix properties (to a greater degree an epoxy one) have changed slightly. Therefore, if previously, the delamination initiated arisen mainly due to incorrectly chosen technical process that resulted in the increased porosity, the low adhesive strength of fiber-matrix interface, etc., then now they often are the main fracture mode for the high-quality plastic material, even at absence of inplane loads what doesn't allow to use maximally the reinforcement strength properties.

This CFRPs feature results in their extra-sensitivity to inplane loading. For the correctly designed airframe the stresses generated by inplane loads, are usually essentially less than stresses in component plane. Due to it, for the current calculation methods these stresses are secondary and are simulated at lower accuracy. Therefore, it is very important when calculating the CFRP elements to simulate all potentially possible interlayer fracture modes and to validate experimentally the correctness of modeling by Building Block.

The delamination problem is aggravated by the lack of reliable methods to detect them nowadays that, among other, is related with the delamination initiation nature: first, the microcracks appear, which do not reduce practically the material strength characteristics. Their aggregating in a macrocrack has an explosive, brittle character. Moreover, the S-N curve exponent for delamination mechanism fractures has considerably lower values, as compared with reinforcement fracture forms, that does not allow to use for delamination the non-growth damage approach described in section 2. All aforesaid has led to the fact that certification authorities both in the Russian Federation, and abroad don't allow the initiation of delamination in CFRP structure during aircraft operation. In particular, in [2] it is said: "Found out at all tests stages or in operation of adhesive (interlayered) damages, demand immediate actions to ascertain the specific reason of their initiation and also to stop the operation of the damaged aircrafts and to carry out the inspection and repair".

Due to high danger of delamination initiation in structure when designing it is necessary to reduce the level of active stresses, which can lead to developing the delamination, which are below the endurance level and when substantiating the life to show that:

- at presence of delamination generated by any reason during operation, there is no its development up to the sizes which reduce the strength below limit load;
- the components, which arrest the development of delamination (e.g. the mechanical fasteners) provide the design strength not below the limit load at presence of delamination along the entire range between such components.

Conclusion

Basic regulations and approaches are stated, used currently to assure the equivalence of full scale life tests of composite-metal airframes to standard operation conditions, developed based on analysis of experience and certification of a number of foreign and national CFRP aircraft structures, including:

- The tests of two identical serial full-scale structures: the first structure was to verify the metal components fatigue service life; the second one was to verify the composite components life;
- The loading spectrum for full-scale tests of CFRP structure is developed accordingly to the existing principles for metal structures; its values are multiplied by the load-enhancement factor and corrected the spectrum obtained to take into account the CFRP behavior features and tests environment;
- Including the test-analysis researches (building block), which is intended to proof the structural integrity and life; to determine the fatigue characteristics for all failure modes for all structural concentrators, which determine the structural integrity taking into account the climatic and operational effects.

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Acknowledgments

The research was financed by Ministry of Education and Science of the Russian Federation, under agreement No.RFMEFI62518X0044 (FENIKS). The authors wish to greatly acknowledge the project partner of FENIKS, Irkut Corporation.

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