FATIGUE LIFE ESTIMATION OF STRUCTURAL ELEMENT OF MI-24 HELICOPTER

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Abstract

Operated helicopter is submitted to varying loads spectrum. Important, for the sake of assurance structure integrity, is definition of the actual value of loads which act on individual structure element. The object of this analysis was the Mi-24 helicopter swashplate lever arm. Life estimation of this element with analytical method, for the sake of complicated geometry, can be problematical. It would be necessary to use considerable generalization which would certainly decrease results reliability. Numerical analysis allows one to create arbitrary shapes but it is necessary to properly define boundary condition.

These work presents methodology for determining fatigue life of the structure element with use of strain gauges, which serve to define the real flight loads. Next step was to determine accurate element shape with the aid of 3D scanner ATOSIII. Geometry was imaged in CAD/CAM environment. After importing the geometry model to MSC.Patran the numerical model was developed. The analysis was done in the scope of linear static analysis. Estimation of fatigue life was done with the aid of MSC.Fatigue computer program. Fatigue life was estimated according to the Palmgren's - Miner's cumulation damage rule.

Test was done in order to define potential fatigue damage sites and defining fatigue life of element. That allows verifying plane overhaul life and fully using helicopters potential next to keeping requested level of safety.

Keywords: *fatigue life, damage, S-N curve, spectrum loads, numerical calculations*

1. Introduction

In the process of the exploitation, helicopter is subjected to changeable spectrum of loads. Essential, for the sake of assurance integrity of the structure, is determining real levels of loads which work on individual elements of the structure. Definition of these loads in the analytical way is very problematic and laborious. We should accept considerable generalizations what would reduce the credibility of obtained results. Numerical analysis allows creating any shapes but it requires defining correct boundary conditions. It is necessary to determine what loads shall be subject to the element in the experiment.

This article represents element's fatigue life of Mi-24 helicopter with use of strain gauges, which were used to define real loads of element during the flight. Obtained data were used to determine the potential damage and to determine the life (fatigue life) of these elements using the rule of the linear accumulation of damage with Palmgren's - Miner's method, according to sum of damage is directly proportional to a number of cycles of the load. This sum increases from 0 to 1 at the time of tested element destruction. Fatigue is the number of cycles of the changeable stress and strain of a certain character that a given material can withstand before it comes to his downfall. S-N curve (Wöhler's) shows the fatigue life at different sizes of the changeable stress.

In case of the fatigue life during testing the group of identical samples we obtaining the considerable scatter of results what it shown on the above graph. On their basis we can construct the S-N curve to accommodate the designated points during testing. The most common form of mathematical curve functions are presented below:

$$N^{-b}S = SRI1, \tag{1}$$

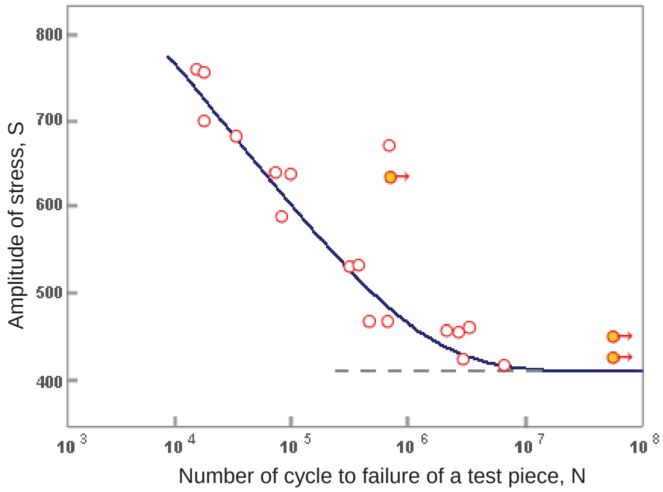

Fig. 1. Example of the S-N curve

$$\log N - \frac{1}{b}\log S = -\frac{1}{b}\log SRI1\,, \tag{2}$$

$$NS^m = k\,, \tag{3}$$

$$\log N + m\log S = \log k\,, \tag{4}$$

$$S = \begin{cases} SRI1(N)^{b1}, & for\ \ N < NC1\,, \\ SRI1(N)^{b2}, & for\ \ N > NC1\,, \end{cases} \tag{5}$$

$$S = S_{\inf}(1 + A/(N+G)^m)\,. \tag{6}$$

where:
N - number of cycles,
S - amplitude of changes of stresses,
SRI1, b, k, m, and, G, S_{inf} - mathematical constants.

Connections between constants appearing in patterns (1 - 4) are introduced below:

$$m = -\frac{1}{b}\,, \tag{7}$$

$$k = SRI1^{-\frac{1}{b}}\,. \tag{8}$$

These formulas describe the same exponential relation between stress amplitude and fatigue life. Through the approximation of experimental data obtained from fatigue test we receive average S-N curves. In order to ensure an equivalent level of safety design in terms of fatigue life we should take into account that there is a scattering of real-life terms assigned to the fatigue life of the average S-N curve. Therefore most often used:

- implementing safety factors for the appointed permanence on the basis of the average of the S-N curve,
- making calculations with the estimated probability of structural damage,
- perform calculations on the basis of the safe S-N curve.
- the creation of safe S-N curve is to bring to a minimum the likelihood of damage to the calculated time.

To determine the safe S-N curve based on the average S-N curve we can use two safety factors:

- LF life factor,
- SF stress factor.

The average S-N curve is reduced by the coefficient value of the LF and next shifted to the left by coefficient value of SF.

Safe S-N curve is the lower envelope of the two curves formed by moving average S-N curve. The envelope takes the shape similar to the average S-N curve (Fig. 2). The way it is set is described in the DEF norm STAN 00 - 970. This standard applies to fatigue of aircraft structures and is used in many countries.

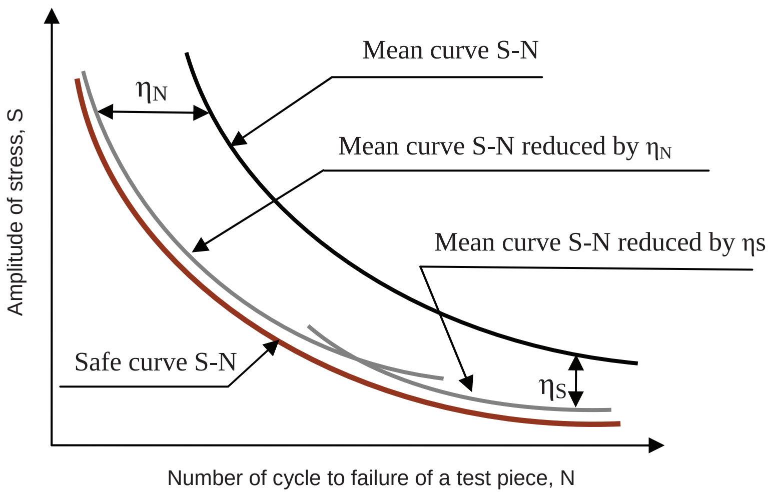

Fig. 2. Graphical representatives of the safe S-N curve, based on safety factors

2. Course of examinations

The object of research was lever arm of swashplate collective pitch control of helicopter rotor Mi-24. Extensometer sensors were stuck to the top and bottom shelf of right and left shoulder in order to calibrate extensometers (Fig. 3). The element was gradually loaded in direction perpendicular to its axis at the MTS testing machine. Then after reassembly on the helicopter - indications were read from KAM-500 recorder. This allowed for the designation of specific loads occurring during flight. The resulting spectrum loads were used to analysis of the fatigue life (Fig. 5).

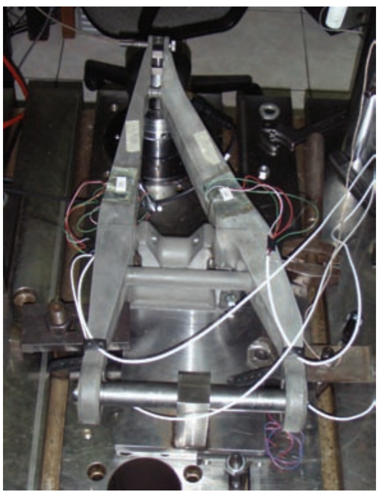

Fig. 3. Method of attachment and feeding loads on lever arm of swashplate collective pitch control of helicopter rotor

The spectrum loads shows the course load in time during the operation conditions. These loads usually have character varying amplitude. Fig. 4 illustrates an example of load-time history.

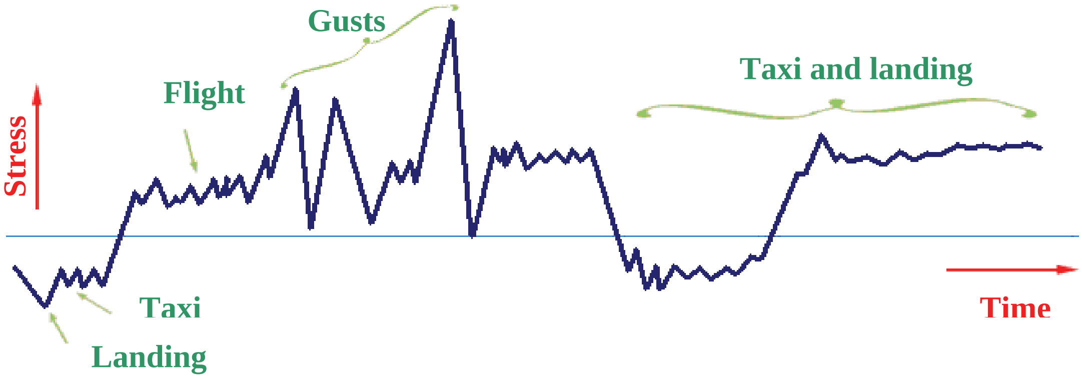

Fig. 4. The example of the influence of the number of thermal shocks on the deformation of the piston sample

The following is a record of loads occurring during flight determined on the basis of the extensometers.

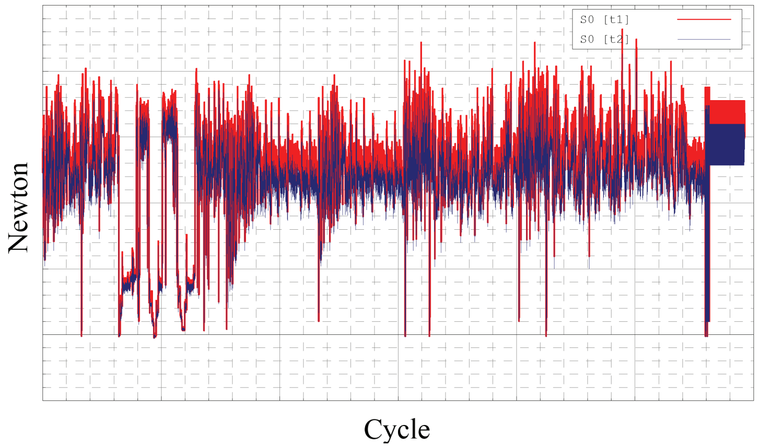

Fig. 5. Graphs of deformations recorded in flight

To measure actual shape were used optical scanner 3D ATOSIII (Advanced Topometric System). During the scan on the measured object, stripes are projected which are then recorded by two cameras. The measurement result obtained by a model composed of a number of triangles which allows mapping the characteristics shape of measured object. It is possible to collect the coordinates of points lying on the scanned elements surfaces in size from a few millimetres to tens of meters. The following figure shows a model made in the ATOSIII system under lever arm test (Fig. 6 a).

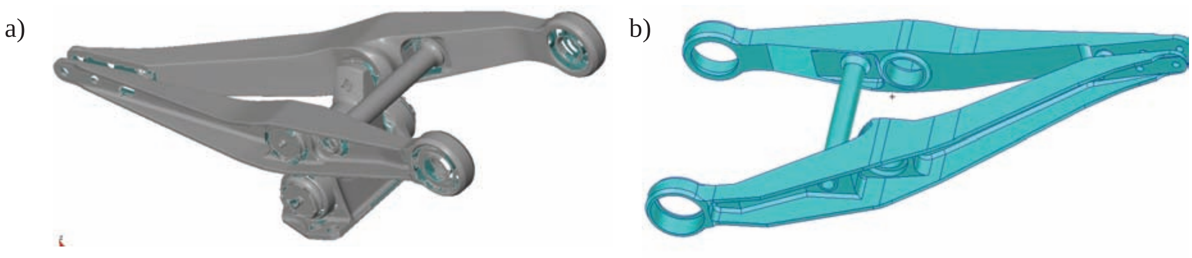

Fig. 6. Model: a) ATOSIII 3 D carried out in the system, b) Unigraphic carried out in the program

On the basis of obtained measurements in the ATOSIII system we mapped element shape in the CAD/CAM environment. The geometrical element model was performed in Unigraphic's program (Fig. 6 b).

Geometric model has been imported to MSC Patran program to create lever FEM model which has 66410 type tet4 elements and 17869 nodes.

The FEM model was constrained by means of blocking all displacements on half of the surface of holes shown on figure below (Fig. 7 a). The centre hole of the lever arm was fixed based on a cylindrical coordinate system but angle displacements weren't blocked (Fig. 7 b).

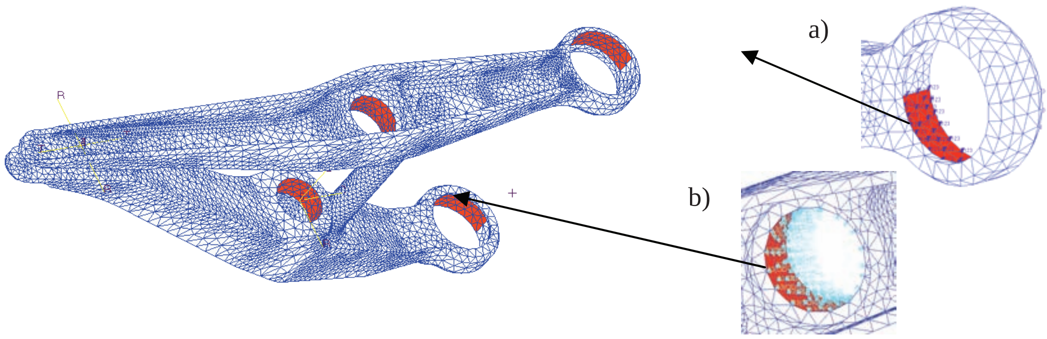

Fig. 7. Confirming the lever: a) on the half of the area of the hole, b) on the entire surface of the hole

Two load cases were taken into consideration. The first load was perpendicular to the axis of the unit force acting downward, second upward. Power load model were made by applying pressure to the finite elements lying inside the holes (Fig. 8).

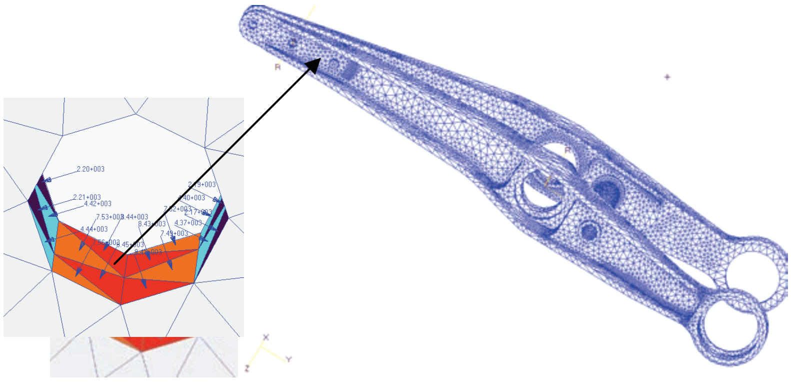

Fig. 8. Straining the lever into the bottom by putting the pressure

Numerical calculations were made using MSC.Marc program. The analysis was performed in linear static range. Fig. 9-10 shows distribution and values of stress reduced according to the effort hypothesis (Huber's). Fig. 10 shows obtained distribution and maximum main stress values. Obtained results concern the individually loaded lever.

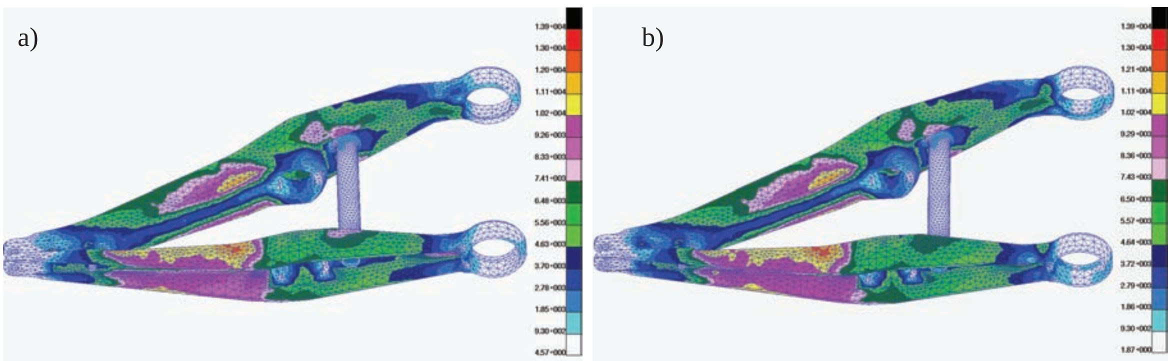

Fig. 9. Reduced stress pattern in the lever a) loaded into downward, b) loaded upward

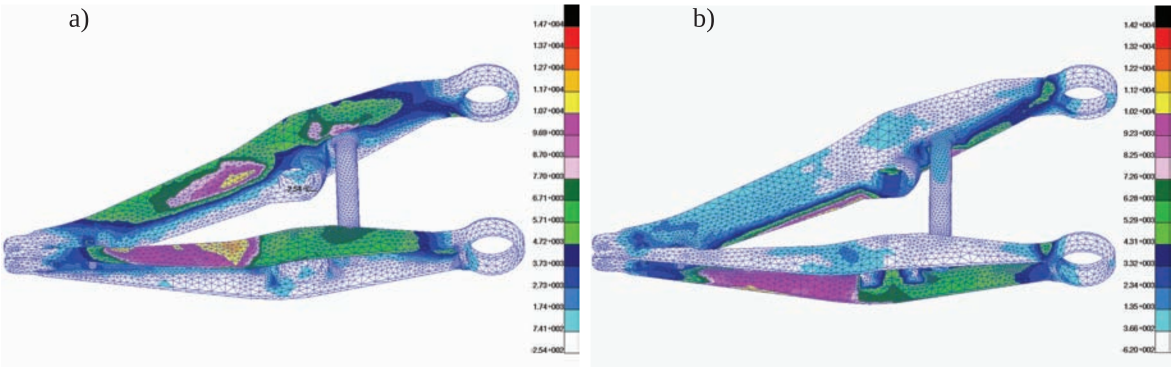

Fig. 10. Maximal main stress pattern in the lever a) loaded into downward, b) loaded upward

Load forces recorded during the flight for the maximum value of the effort material in lever for the down load is equal to 368 MPa (upward 854 MPa), whereas the maximum value of the maximum main stress is equal to 389 MPa (upward 872 MPa).

3. Computer analysis of the fatigue life

Fatigue life calculations performed using a computer program MSC.Fatigue which is tightly

integrated with the MSC.Patran environment. This software allows you to enter data in the form of FEM model, data material and load waveforms. On the output obtained files contain numerical model with results. Fatigue test of 35HGSA material was used for the calculations. MSC.Fatigue brings safe S-N curve for the two curves described the relationship:

$$S = \sum_{i=1}^{i=2} SRI_i \cdot N^{bi} \ . \qquad (9)$$

where:

N - fatigue life,

S - stress range,

SRI_i - stress range intercept,

b_i - factor of inclination i-function.

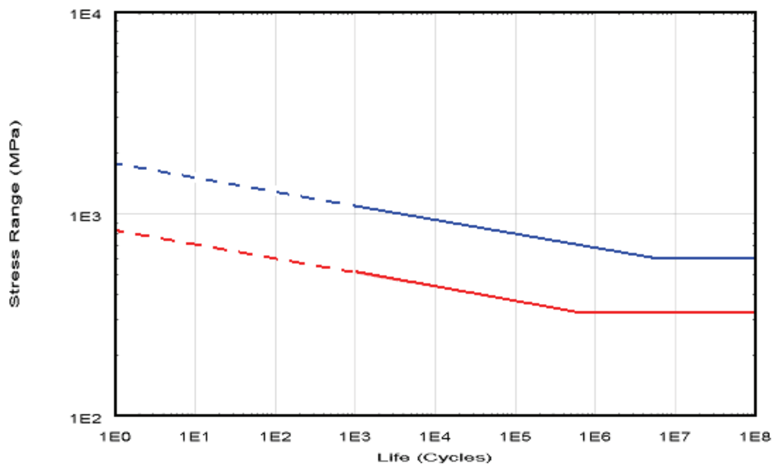

Fig. 11. Safe and medium S-N curve for 35 HGSA

Below the results are shown.

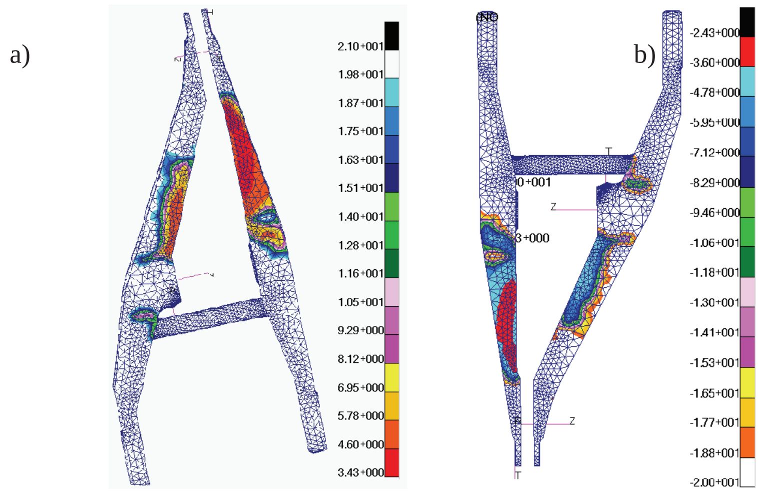

Fig. 12. a) Logarithm of fatigue life, b) logarithm of fatigue failure

The fatigue life of the lever at spectrum load recorded during the testing flight is equal to 6727 h.

4. Conclusions

Determination of fatigue life is difficult processes, whether through computer simulations, or through tests on the real model. However computer methods allow significantly reduce the time of the project.

The area of maximal effort in the element is in the region of the lower and upper shelves.

The level of stress generated in the elements of strength does not exceed the yield point of material. Obtained results do not undermine the durability determined by manufacturer for tested elements. The research allows determining how to shape durability of individual element using appropriate research methods.

The study was performed to determine the potential damage and life (fatigue life) of the element. This allows verifying overhaul life planes and taking full advantage of helicopters potentials while maintaining the required level of security.

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