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FATIGUE LIFE ESTIMATION OF THE TAIL BOOM AND VERTICAL STABILIZER OF MI-24 HELICOPTER

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Abstract

The aim of this work was to estimate fatigue life of the Mi-24 helicopter tail boom and vertical stabilizer sheathing. The analysis was based on a numerical model of the helicopter airframe crucial to obtain stress fields under defined loads and to estimate fatigue life.

In order to do so, the load spectrum, specific for Polish army helicopters, was obtained by means of strain gauge measurements during a series of experimental flights. Data collected during flights was post-processed to create a characteristic ten hour spectrum that would statistically represent the flight profile for Polish Army Mi-24 helicopters.

The third crucial element of the analysis was the safe S-N curve that was created on the basis of 2024-T3 aluminum S-N curve. Two factors were introduced in order to change the curve in a way that would guarantee a higher level of certainty that the outcome is not overrated.

As a result of this analysis the total fatigue life was estimated including the list of critical locations in which fatigue damage is prone to occur. These regions are going to be carefully examined during scheduled inspections.

1. INTRODUCTION

Fatigue is a very important problem as it comes to aircraft structures. Variable levels of loads maintained during long term operations can cause a damage that may not be found during regular inspections for a long time and accumulate to create a fatal failure as is the case of wide spread damage. When it comes to helicopters the risk is even higher since the load spectrum for these types of aircraft is usually more complicated and a higher number of cycles is accumulated during the same amount of time.

Mi-24 helicopters have been exploited all around the world for decades. Data that come from the manufacturer are strictly dependant on the assumed flight profile and the estimated fatigue life may vary from the expected one. It is known that for two different load spectra, fatigue life of a specimen will differ and in order to estimate a reliable fatigue life one must take into consideration specific conditions in which the specimen, in this case a helicopter, will operate.

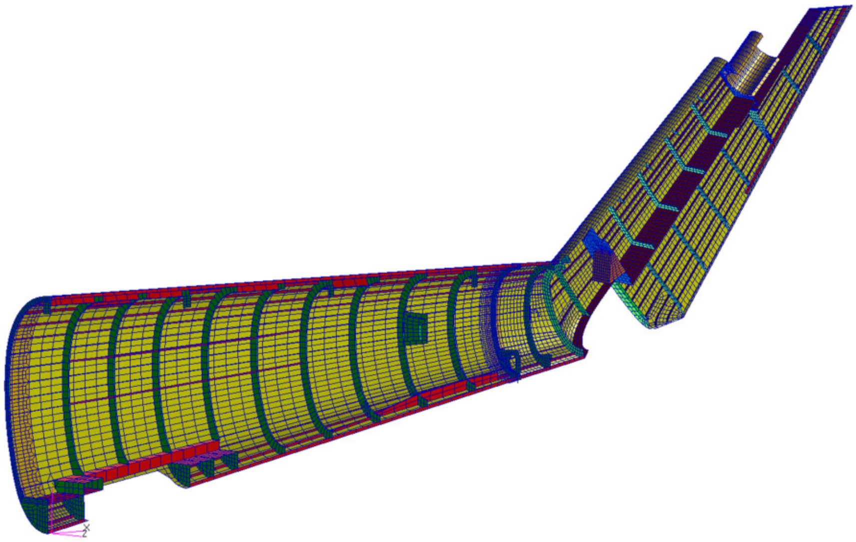
Hence the Air force Institute of Technology has undertaken a numerical analysis whose aim was to estimate fatigue life of the sheathing. The crucial elements necessary to carry out such estimations are: the stress field in the airframe under considered flight loads, the load spectrum that will represent the characteristic flight profile, and a reliable S-N curve. This article describes step by step how these elements were obtained and combined together to obtain reliable fatigue estimation.

The numerical model as well as stress estimation and fatigue calculations were made in MSC Software applications.

2. NUMERICAL MODEL

The finite element method model used in this analysis was created in the MSC Patran environment. The detailed geometry of the airframe was obtained by means of reversed engineering which included digital photogrammetry and three dimensional laser scanning.

The inner elements were created on the basis of a detailed inspection and the available documentation. Altogether the model of the tail boom and vertical stabilizer consisted of about 24 000 elements.



Pic. 1. View of the right hand side half of the numerical model

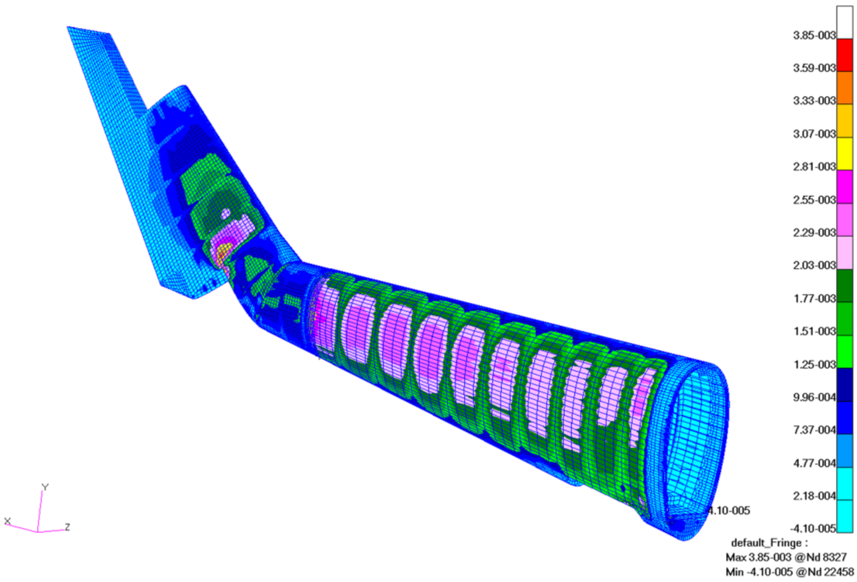
The majority of the elements used in the model were thin walled quad elements with six degrees of freedom in a node to consider effect of bending. The strength elements such as ribs or transmission boxes were represented with brick elements. Bar and beam elements were introduced for slender structure elements, such as stringers reinforcements, or when the element geometry was not relevant but its mass was significant, like in the case of horizontal stabilizer.

The elements were divided into groups, as highlighted with different colors in the picture above, in order to ease further modifications and to allow separate calculations for a particular group.

The booms connection to the rest of the airframe was represented by constraining all six degrees of freedom in the nodes whose location corresponds to the location of bolts connecting the boom and the fuselage. To optimize the boundary conditions, a part model of the fuselage back, not included in the above picture, was used to eliminate any local effects due to fixed support.

Of all the flight loads to which the airframe is subjected, the three dominant ones were chosen, which have significant influence on the structures stress field. Those loads are: the bending moment in the vertical plane caused mainly by maneuvers, particularly landing, the bending moment in the horizontal plane as well as torque, both caused by rear rotor thrust. Since rear rotor thrust causes both torque and bending moment in the horizontal plane, the real bending moment used in computations had to be carefully defined in order not to overload the structure.

The main purpose of the numerical models was to determine stress fields for the above mentioned loads normalized to unity loads. This allowed using these fields directly in MSC Fatigue software with the load spectra which were represented by the varying value of load. The analysis was based on the maximal principal stresses.



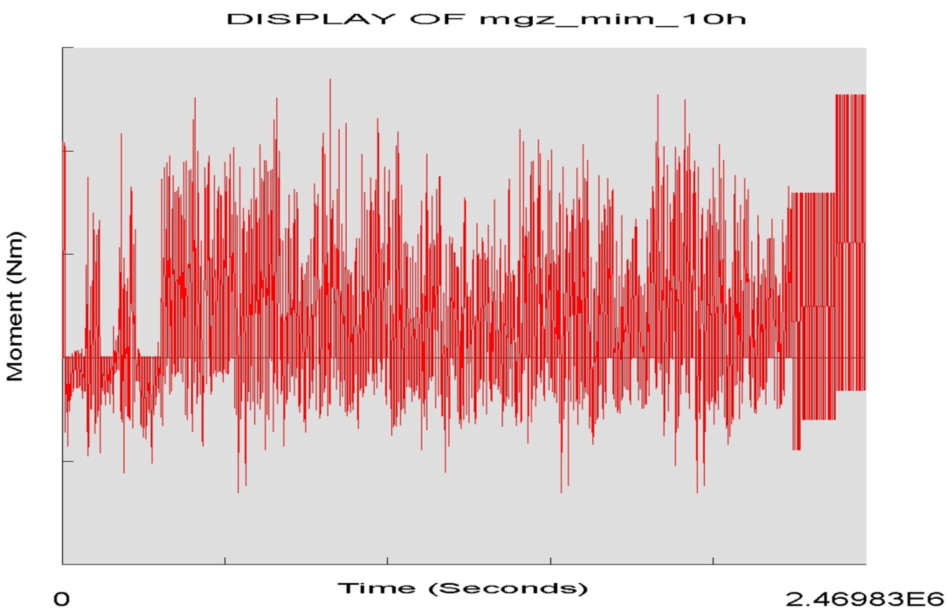
Pic. 2. Example stress field caused by the unity load of the rear rotor thrust

3. LOAD SPECTRUM ESTIMATION

Although there are several load spectra available for helicopters, AFIT decided to evaluate a representative ten hour spectrum characteristic for the Mi-24 helicopters. In order to do so an array of strain gauges was designed and installed onto airframe to gather coherent strain signals during flight.

After installation, the system was scaled using defined loads applied to the structure, which enabled creating linear regression equations describing flight loads by means of measured strains. The direction of calibration loads for the tail boom and vertical stabilizer was adequate to the three loads mentioned above.

The experimental flights were specially designed to fully represent the missions and particular maneuvers that are most common during exploitation. After the flights, data was gathered and post processed and three ten hour load spectra were obtained, representing statistical loading of the airframe.



Pic. 3. Example load spectrum for the bending moment in horizontal plane

4. FATIGUE LIFE ESTIMATION

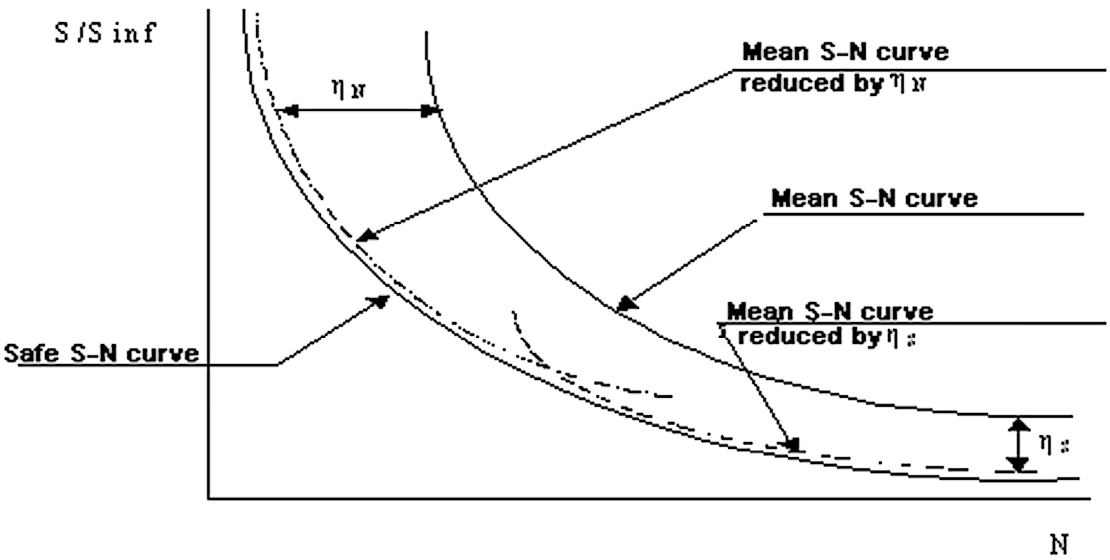
The last crucial element of the analysis, the S-N curve, was determined in the MSC.Fatigue software. The curve, which represents the stress range versus the number of cycles, plays a significant role in fatigue estimations and must be chosen carefully. Since the S-N curves are obtained on the basis of experimental tests one must be aware that during such tests a noticeable spread is common. The curves created after such tests are usually so-called mean curves, which means that one can expect to obtain values both higher and lower than the one stated by the curve.

To prevent the latter from occurring, the safe S-N curve is created to ensure that the fatigue life will not be overestimated. Based on the 2024-HV-T3 aluminum, which is the best representation of the D-16 aluminum in the programs library, a safe S-N curve was created. This was accomplished by introducing two factors which decrease the number of cycles to failure. The factors used are listed in the table below.

Table 1. Safe factors for the safe S-N curve

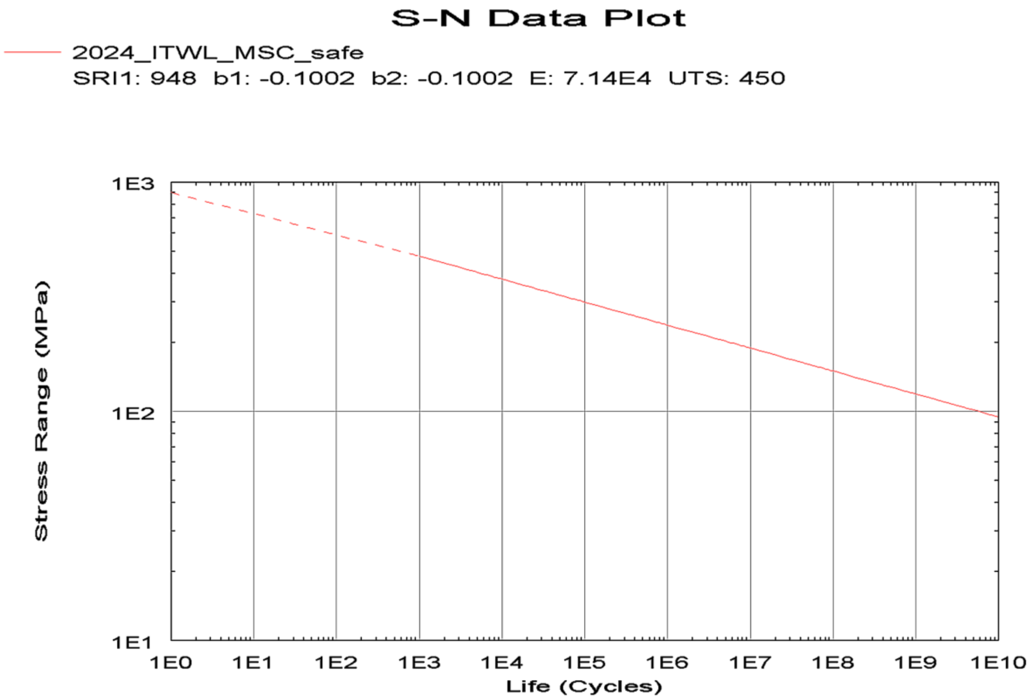
Safe factors in respect of fatigue life in the low end of S-N curve η_N	**safe factors in respect of stress in the high end of S-N curve** ηS
basic factors	
$\eta_{N1} = 2.8$	$\eta_{S1}=1.49$
additional factors (no load monitoring)	
$\eta_{N2} = 1.5$	$\eta_{S2}=1.2$
additional factors (no fatigue tests for considered elements)	
$\eta_{N3} = 2.0$	$\eta_{S3}=1.2$
output factors (iloczyn współczynników)	
$\eta_N = 8.4$	$\eta_S=2.15$

The safe S-N curve is the envelope of the two curves obtained by introducing the above mentioned factors.



Pic. 4. Graphical representation of the safe S-N curve creation

The S-N curve gives information about life cycles for a certain stress range with respect to the zero mean stress. The obtained load spectra have mean stress values different than zero so a mean stress reduction had to be considered. In this analysis the Gerber stress reduction theorem was considered. The obtained safe S-N curve is shown in picture 5.



Pic. 5. Bilinear safe S-N curve in MSC Fatigue

Since the global FEM model, used in computation, did not include rivet holes that cause stress concentrations, an additional factor for stress level multiplication of value 2.3 was used to ensure that those concentrations were taken into consideration.

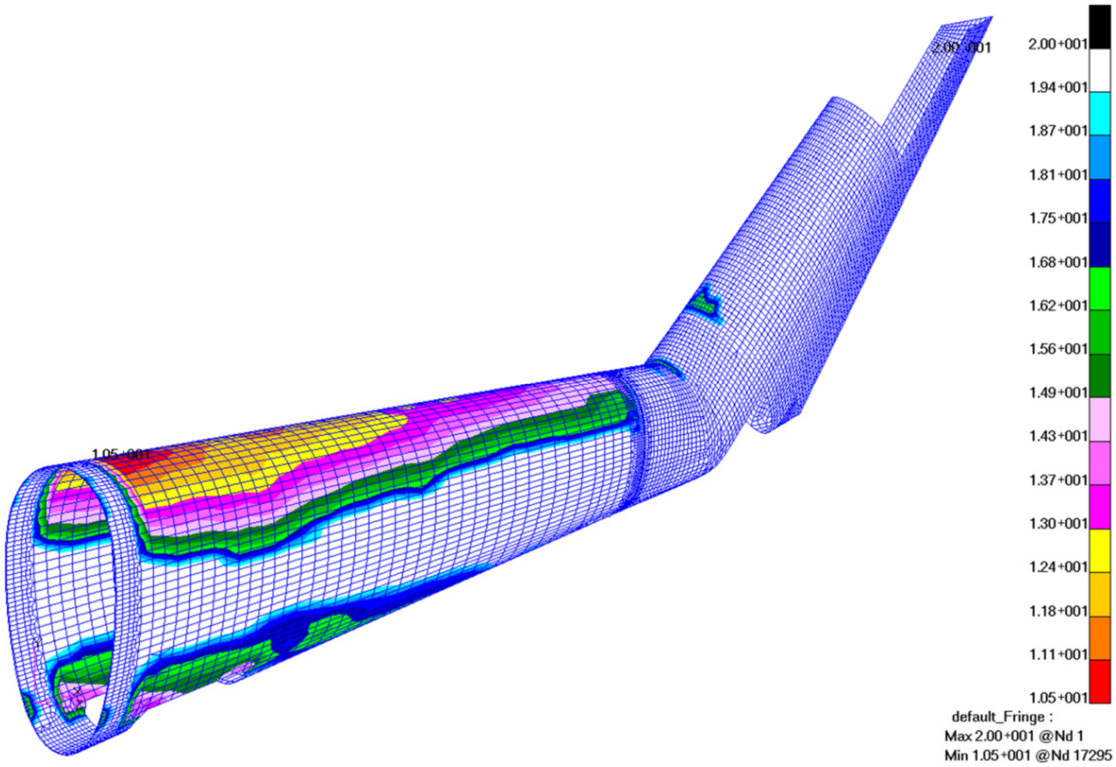
The material properties and characteristic MSC Fatigue material factors used in the analysis are listed in the table below.

Table 2. Material properties used in MSC Fatigue.

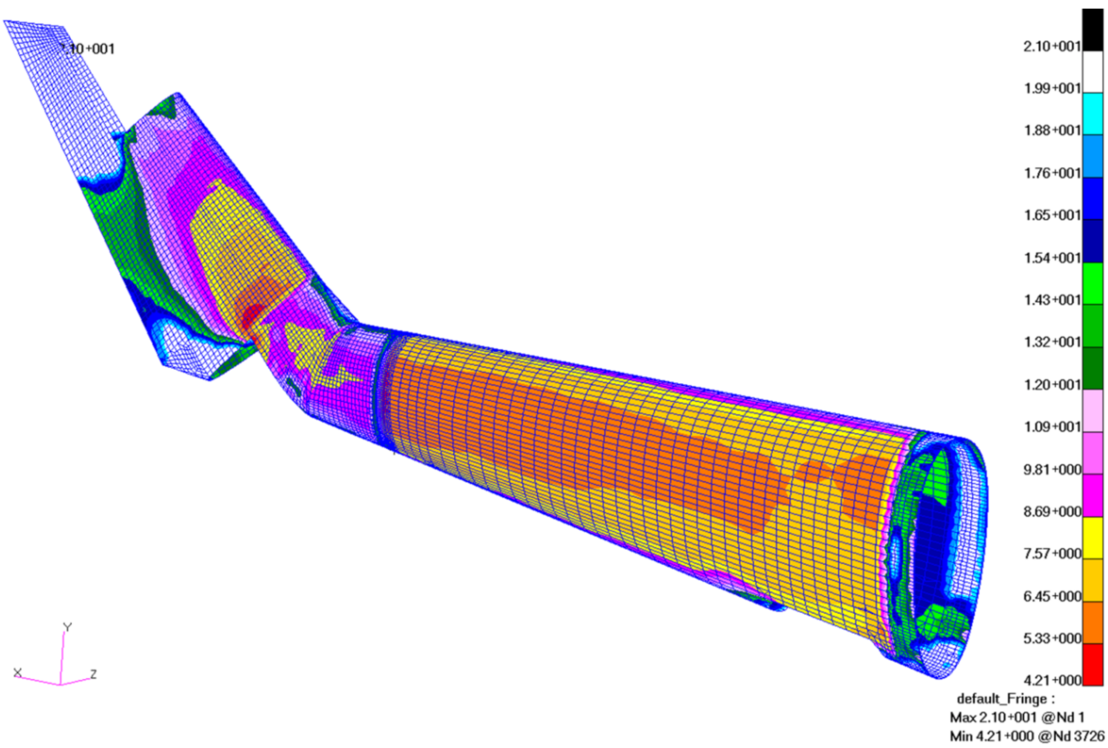
Property	**Value**	**Units**
Young modulus (E)	7.14E4	[MPa]
Poisson's ratio	0.3	[-]
Tensile strength Rm (UTS)	450	[MPa]
Yield strength Re	320	[MPa]
Density	2700	[kg/m^3]
SRI1	948	[MPa]
b1	– 0.1002	[-]
b2	– 0.1002	[-]
NC1	1.2E5	[-]

5. RESULTS

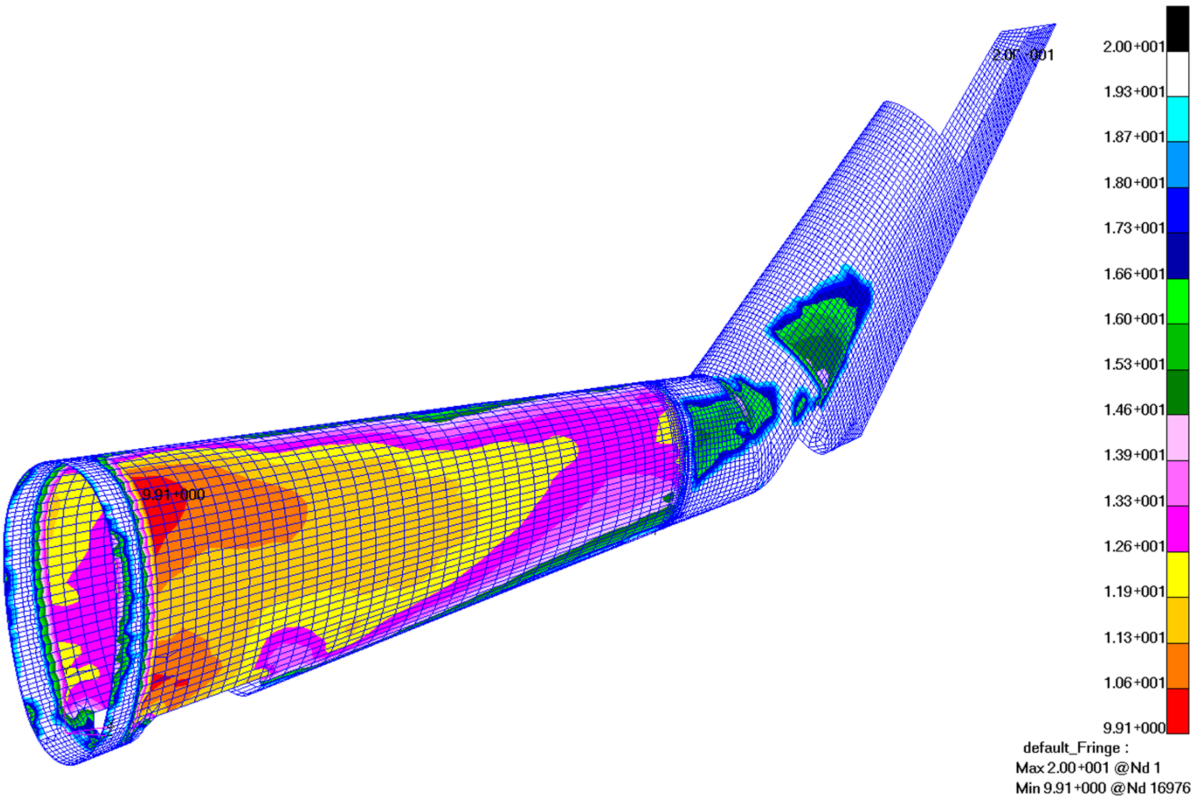
As a result of the calculations, the fatigue life for each load was obtained. The obtained results are presented below. MSC Fatigue post processing options allowed creating a resultant fatigue life for a complex load, which is also presented below.



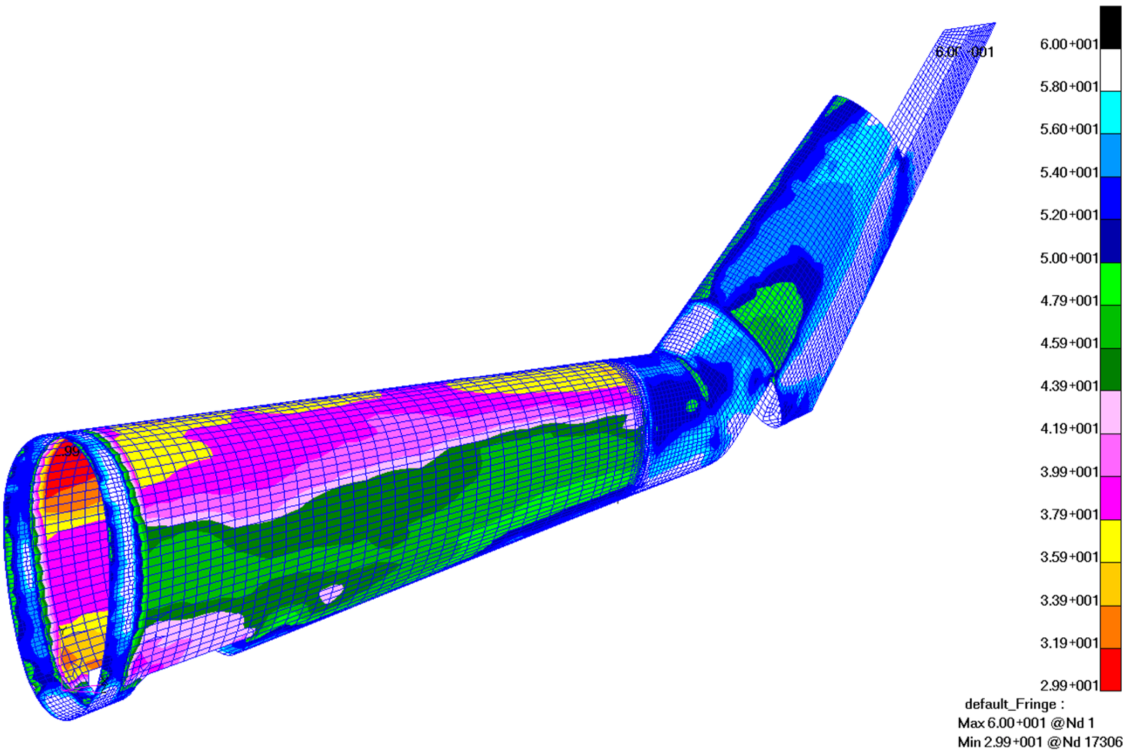
Pic. 6. Fatigue life due to bending moment in vertical plane, logarithmic scale



Pic. 7. Fatigue life due to torque, logarithmic scale



Pic. 8. Fatigue life due to bending moment in the horizontal plane, logarithmic scale



Pic. 9. Total fatigue life, logarithmic scale

The analysis determined the critical locations where fatigue damage may occur. Damaged regions were located in the vertical stabilizer, where the horizontal part meets the skew one and on the circumference of the tail boom near the collar connecting it to the rest of the fuselage.

The presented estimation allowed predicting fatigue life of the sheathing to be 6200 flight hours. The load that had most influence on the airframe fatigue life was the bending moment in the horizontal plane caused by the rear rotor thrust.

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