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THREE-PARAMETER OPTIMISATION OF AN ATTACHMENT LUG

TROPARAMETARSKA OPTIMIZACIJA UŠKE ZA VEZU

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Keywords
- attachment lug
- finite element method
- SMART
- fatigue crack growth

Abstract

Three-parameter optimisation of a wing-fuselage attachment lug was applied to its thickness, rounding radius, and radius of pin hole, using the fatigue life and mass as criteria. Numerical simulation of fatigue crack growth by finite element method (FEM) and Separating Morphing and Adaptive Remeshing Technology (SMART) was used to evaluate the number of cycles up to critical crack length.

Ključne reči
- uška
- metoda konačnih elemenata
- SMART
- zamorni rast prsline

Izvod

Troparametarska optimizacija uške za vezu krilo-trup je primenjena na debljinu, radijus zaobljenja i radijus otvora, uzimajući zamorni vek i masu kao kriterijume. Numerička simulacija zamornog rasta prsline je urađena metodom konačnih elemenata primenom Separating Morphing and Adaptive Remeshing Technology (SMART) da bi se odredio broj ciklusa do nastanka prsline sa kritičnom dužinom.

INTRODUCTION

Since all loads from the wing are transmitted to the wing-fuselage attachment lug, Fig. 1, the importance of its accurate design, especially against fatigue damage, cannot be overestimated, /1/. One should also keep in mind that according to Federal Aviation Administration regulations these attachments are not the subject of experimental verifications since they are designed as safe-life components, /2/. However, some recent events in commercial aviation indicated the need to consider the fail-safe design as well, since cracks were found after less time in service than meets the threshold for mandatory inspections, forcing many airlines to check their airplanes and search for a solution to this problem, /3-4/. Some aspects of this problem are tackled in /5-9/.

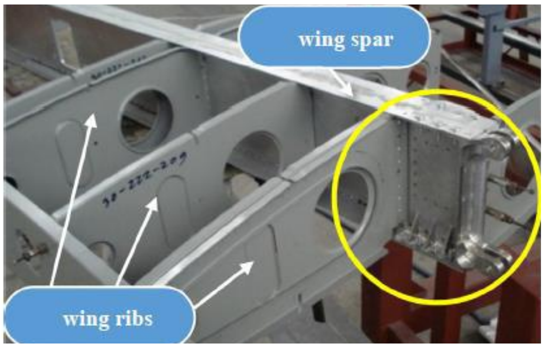

Figure 1. Light aircraft wing-fuselage attachment, /11/.

In this paper three-parameter optimisation is presented with the goal to prolong fatigue life of the damaged lug without excessive increase of mass (fail-safe approach). The light training airplane is used as an example, where extensive analysis of forces acting on the attachment wing is made, /10/, and two-parameter optimisation performed, /11/. Application of FEM and extended FEM (XFEM) simulation of fatigue crack growth in the attachment lug is described in /12, 13/, pointing out the main difference - unlike the XFEM method, as implemented in Abaqus®, where there is no re-meshing during the simulation, mesh around the crack front in classical FEM changes and adapts with every growth step using Separating Morphing and Adaptive Remeshing Technology (SMART) as built in Ansys®. In paper /12/ both methods of fatigue crack growth simulation are presented and analysed for two different crack configurations - penny-shaped corner crack and edge through-thickness crack. In the scope of XFEM analysis, it was shown for penny-shaped crack that the tetrahedral mesh produces shorter fatigue life and a bit irregular SIF behaviour during crack growth. Also, it was shown that XFEM produces somewhat higher K_I values than SMART FEM, so that fatigue life is somewhat shorter. Paper /13/ is a review article on XFEM simulation of fatigue crack growth with a number of case studies described and analysed, including the attachment lug.

NUMERICAL SIMULATION

Here classical FEM is used for fatigue crack growth simulation in combination with SMART, /12/. Both classical FEM and XFEM are successfully applied in many other problems, as explained in /14-17/. A finite element model with boundary and loading conditions is shown in Fig. 2, while the FE mesh is shown in Fig. 3. Stress ratio R = -1 was adopted in accordance with wing loading, while Paris coefficients n = 2.26 and $C = 7.526 \cdot 10^{-11}$ are taken from /18/, for the high strength steel used for the wing-fuselage attachment lug.

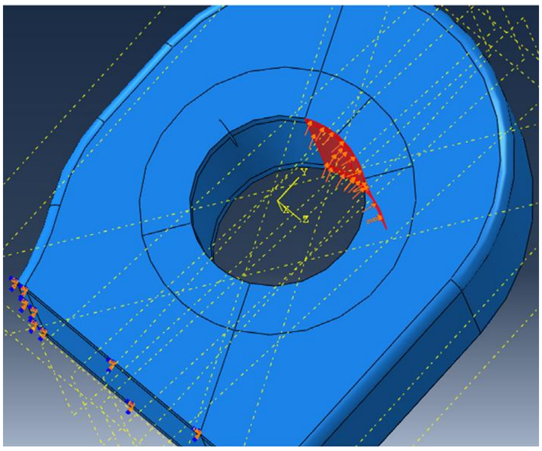

Figure 2. FE model of attachment lug, /11/.

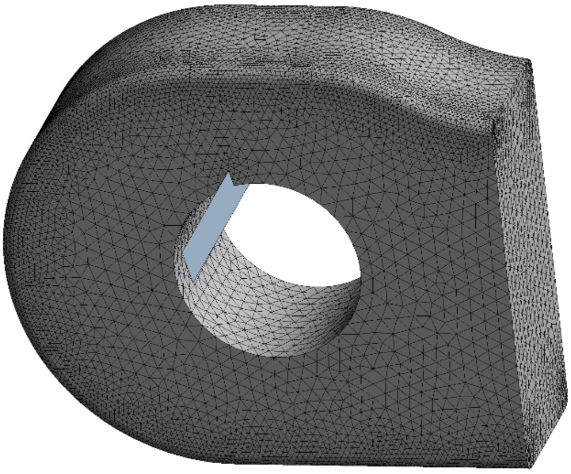

Figure 3. Finite element mesh used in optimisation, /11/.

The SIF values just before the fracture of the attachment lug are shown in Fig. 4, where it can be seen that the crack has grown for an additional 7.37 mm, regarding its initial size (1 mm). The maximal number of cycles N_{max} = 515. Initial mass of the attachment lug was 87 grams.

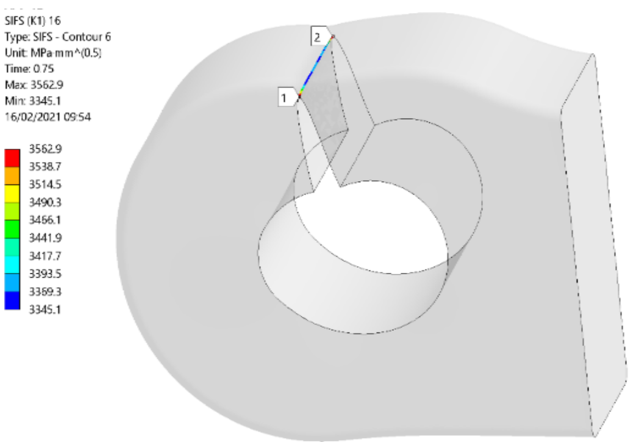

Figure 4. SIF values after the 15th step of propagation.

OPTIMISATION

Increased thickness was modelled as the first step in the optimisation process, /5/. The number of cycles for lug of thickness 17 mm was increased to N_{max} = 1085, i.e., almost double in respect to the original thickness (12 mm), but the increase in mass was excessive, over 40 %. Complete results are shown in /11/, including values of maximal SIF. The next step was two-parameter optimisation, also shown in /5/, with thickness and rounding radius as parameters. It was shown that the SIF values along the crack front for lug thickness of 17 mm and rounding radius of 19 mm are significantly reduced, but the mass was increased 75.8 % (from 87 to 153 grams), so additional parameters had to be included to achieve an optimal combination of mass and fatigue life. This was the reason to perform three-parameter optimisation, as described further.

Three-parameter optimisation of lug

The three-parameter optimisation model included thickness (Fig. 5), rounding radius (Fig. 6), and radius of a pin hole (Fig. 7). Besides them, one ‘non-geometrical’ input parameter was also selected: the initial position of the crack with respect to the surface of the pin hole (Fig. 8). This was necessary because in this case, with geometrical parameters varying, the size of the pin hole is changing, too. So, in order to keep the same initial size of the crack, the crack edge in the shape of a rectangle has to be ‘attached’ to the newly generated pin hole surface (Fig. 8).

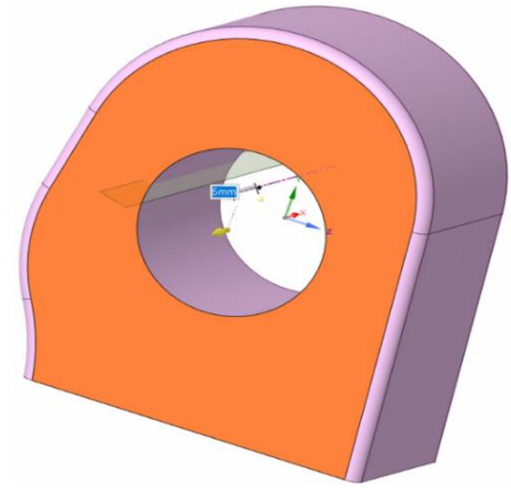

Figure 5. Original lug with increased thickness.

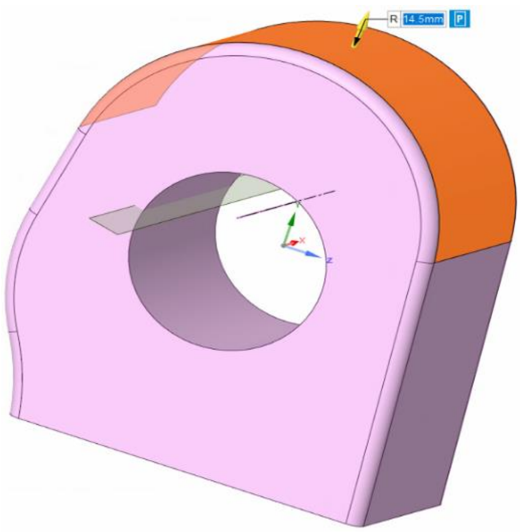

Figure 6. Rounding radius of the highlighted surface.

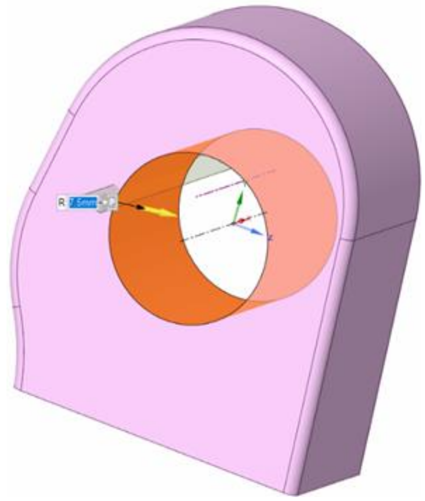

Figure 7. Radius of pin hole (highlighted surface).

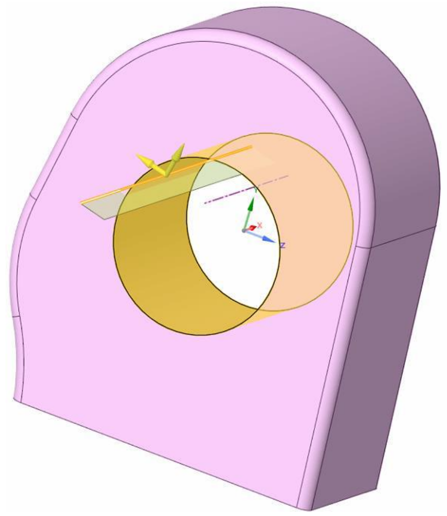

Figure 8. Initial crack position is kept constant with respect to the yellow surface.

In the Design Exploration module of Ansys Workbench®, the total number of $3^3 = 27$ combinations of thickness values and two radii were generated, and the $K_{I\max}$ value for the first crack propagation step was calculated by FEM for each combination (Fig. 9).

Table of Design Points

	A	B	C	D	E
1	Name	P3 - radius	P5 - thickness	P7 - radius 2	P8 - Parameter
2	Units	mm	mm	mm	
3	DP 1	16.94	1.82	7	0
4	DP 2	19	5	7	0
5	DP 6	11.331	-3.521	9.2605	0.01479
6	DP 7	11.331	-3.521	9.2605	0.08521
7	DP 10	17.669	-3.521	9.2605	0.01479
8	DP 11	17.669	-3.521	9.2605	0.08521
9	DP 13	14.5	0	5	0.05
10	DP 17	14.5	0	10	0.05
11	DP 21	11.331	3.521	9.2605	0.01479
12	DP 22	11.331	3.521	9.2605	0.08521
13	DP 25	17.669	3.521	9.2605	0.01479
14	DP 26	17.669	3.521	9.2605	0.08521
15	DP 27	14.5	5	7.5	0.05
16	DP 28 (Current)	19	0	7.5	0.05

Figure 9. Generated design points with selected parameters (r_1 = 14.5 mm, r_2 = 7.5 mm, t = 17 mm).

Some of those combinations gave very high $K_{I\max}$ values or mass values, so they were eliminated from further calculations, so the design points (DP) diminished to 14. As a representative combination DP 27 was selected (Fig. 9), with $K_{I\max}$ = 1267.6 MPa√mm in the first step of crack growth (Fig. 10a) and $K_{I\max}$ = 3548.3 MPa√mm in the last step (15th) (Fig. 10b), providing the mass of 108 grams. The resulting diagram crack length vs. number of cycles is shown in Fig. 11 together with the results for the original lug. For better comparison, crack length is given up to 7 mm. One can now compare mass, initial $K_{I\max}$ and number of cycles, as follows:
- mass 87 g (original), 108 g (optimised), increase 24.1 %,
- initial $K_{I\max}$ = 1880 MPa√mm (original), 1267.6 MPa√mm (optimised),
- number of cycles: 515 (original), 786 (optimised), increase 52.6 %.

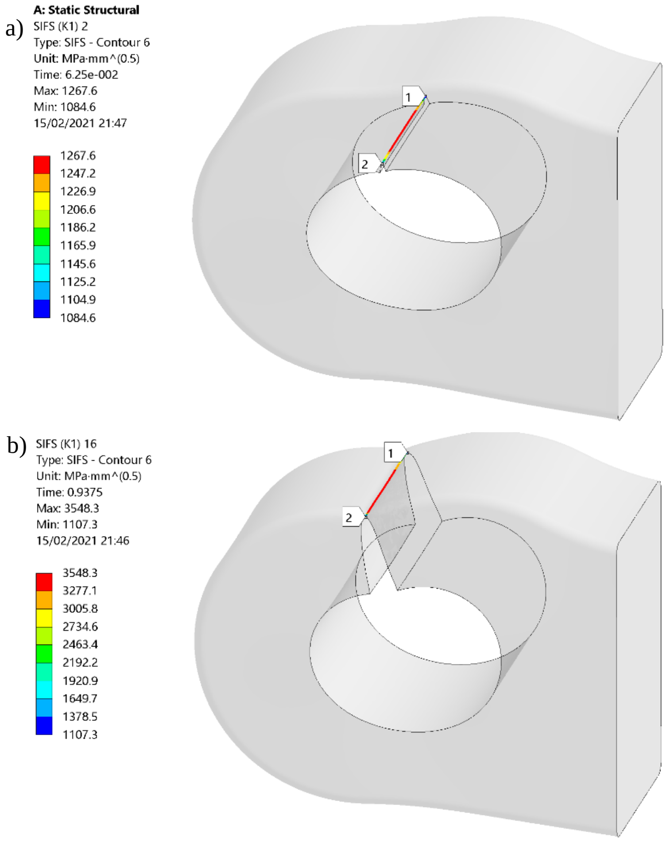

Figure 10. SIF values along crack front: a) after 1st; b) after 15th step.

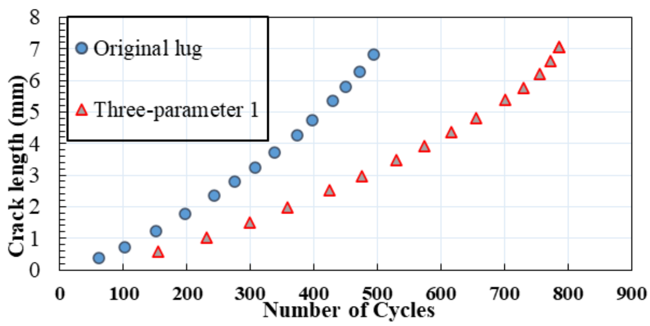

Figure 11. Crack length vs. number of cycles for the lug models.

CONCLUSIONS

Based on the results presented here, one can conclude that the design of the attachment lug presented here increases its mass to some extent, but significantly improves fatigue life which reduces the risk of failure before the crack is observed in regular maintenance inspections.

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