SHAPE MODIFICATIONS OF CRITICAL FUSELAGE PARTS ACCORDING TO FATIGUE DURABILITY

Tomáš KATRŇÁK

IAE FME BUT

Faculty of Mechanical Engineering
Brno University of Technology
Technická 2896/2, 616 69 Brno
Czech Republic

katrnak@fme.vutbr.cz

Martin PLHAL

IAE FME BUT

Faculty of Mechanical Engineering
Brno University of Technology
Technická 2896/2, 616 69 Brno
Czech Republic

plhal@fme.vutbr.cz

Abstract.

The article presents a shape optimization of critical fuselage wall segments and undercarriage spars, a localization of stress concentrations and modifications for a reduction and removing of stress peaks. Structural analyses are made on main fuselage parts on the aircraft in CS-23 Commuter category. There are described main types of proper shape modifications with graphic comparisons and highlighted stress peaks.

Keywords: Fatigue durability, Fuselage, Spar, Stress peak.

1 Introduction

There are main proper solutions of shape modifications for a fatigue durability enlargement introduced in this paper. In our case on the small transport aircraft in commuter category there was selected critical fuselage parts as undercarriage spars and wall segments, because they limits the fatigue durability of fuselage and entire aircraft. Modern methods for an inspection of critical concentrators were not used on these parts before. Therefore advanced finite element methods with special modifications could improve particular critical regions.

Final functional modifications are clearly presented in this article on the undercarriage spar and they were also used on other critical spars and wall segments.

Shape modifications could be proved on the validated FE model. First was created original geometry model which was designed identically to a spar model used in the experimental structural test with the same boundary conditions, attached parts and loads. Then validation of FE model was confirmed by result comparisons from FEM analysis and experimental test measurements.

From FE model results were selected five main regions with maximum tension stress levels, which were caused by high stress concentrations. For fatigue durability purposes stress values were indicated as Max Principal stresses. Next were compared stress results in particular modifications. In some cases a low increase of a spar weight is a reasonable price for large fatigue durability profit.

2 Original geometry FE model

The geometrical CAD model of a machined undercarriage spar was obtained from the aircraft producer. Some holes are drilled in setting operations, therefore geometrical model had to be adapted to a final assembly on the aircraft. Also surrounding parts, especially fuselage wall segments, had to be completed and attached to a proper position, which was measured on a real aircraft. The material of an assembled spar model is duralumin alloy 2124 and its final weight is 22.8 kg.

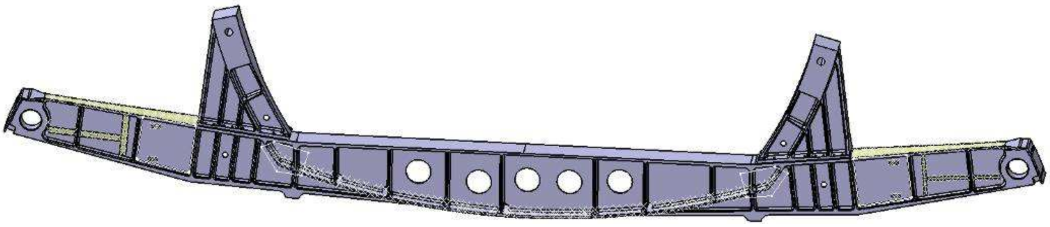

Figure 1: Entire assembly of a critical undercarriage spar with attached parts.

Geometrical modifications of the spar model were made in the software Catia V5 R19. A creation of the FE model and an evaluation was in MSC Patran 2010.2.3 and the structural analysis is computed in software MSC Nastran 2008.1.0 MD R3.1.

For the structural analysis the FE model of the spar and wall segments were meshed with ten-node 3D tetra elements. Parts of skins and attached plates were prepared with 2D Quad and Tria elements. Rivet and bolt connections of particular components were substituted by 1D beam elements connected to hole surfaces by contact GAP elements.

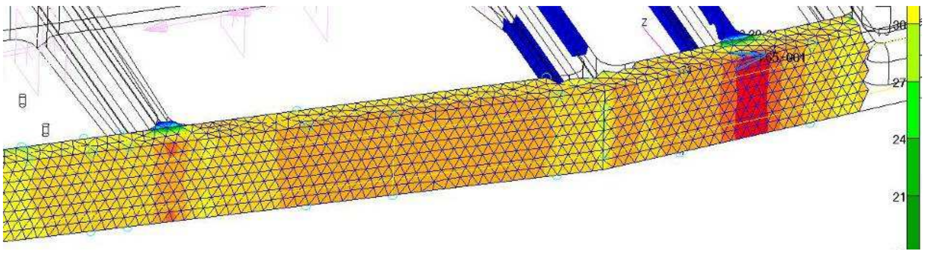

Figure 2: Detail of FE model density.

On the following figure 3, there are an analysis model arrangement, applied forces and boundary conditions.

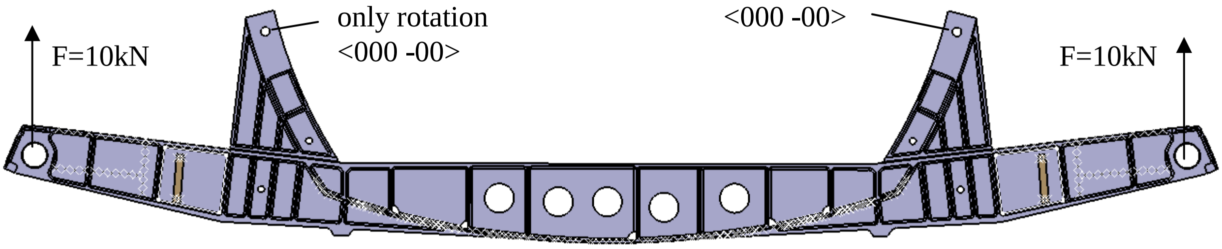

Figure 3: Scheme of the structural analysis model.

Boundary conditions - a rotation attachment in wall segment joints.
Load cases - for an ease of a load conversion was selected spar lug load 10 kN.
Material model - isotropic homogenous linear material with Euler modulus E = 72 000 MPa.
Analysis solution - geometrically nonlinear analysis 106 with contacts solved by MSC.Nastran software

3 Experimental test model

This experimental test arrangement of the undercarriage spar no. 14 obtained from the aircraft producer was used as a template for design of original geometry FE model. On this specimen on figure 4 were attached real surrounding parts and riveting was identical as on real aircraft. Sets of strain gauges were placed on both sides of spar and their positions are shown in figure 5.

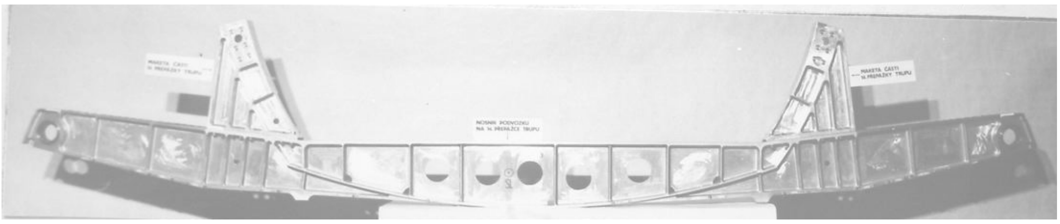

Figure 4: Picture of real test specimen of undercarriage spar.

4 Validation of FEM analysis with test results

Results from FEM analysis was compared with experimental test results. Boundary conditions, an arrangement, assembled parts, points of attachment and forces were identical for both. Therefore measured stresses obtained from strain gauges used in experimental test could be compared with detected stresses in the same locations on FE model spar. Compared values are presented in table 1 and position of strain gauges is shown on figure 5.

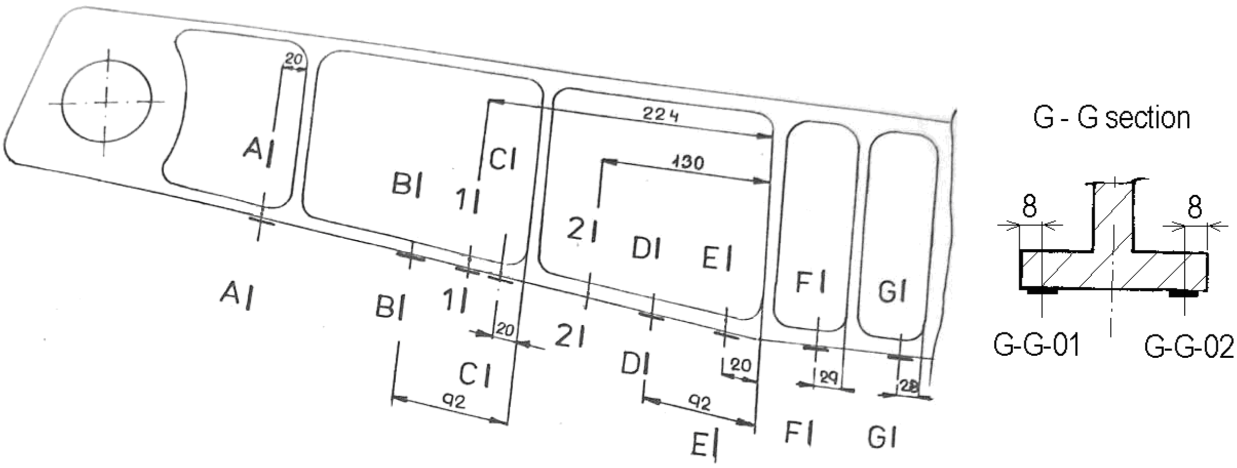

Figure 5: Location of strain gauges on undercarriage spar.

Location	Section	Experimental test stress [MPa]	FEM analysis stress [MPa]	Difference [%]
A-A-01	A-A	25,8	24,47	-5,3
A-A-02	A-A	25,4	24,36	-4,0
B-B-01	B-B	34,5	32,60	-5,5
B-B-02	B-B	33,0	32,50	-1,6
C-C-01	C-C	34,0	33,00	-3,1
C-C-02	C-C	33,9	34,50	1,7
D-D-01	D-D	41,2	39,40	-4,4
D-D-02	D-D	38,8	39,30	1,4
E-E-01	E-E	38,6	36,16	-6,4
E-E-02	E-E	37,0	36,10	-2,3
F-F-01	F-F	38,5	38,20	-0,9
F-F-02	F-F	36,8	38,20	3,7
G-G-01	G-G	33,5	36,30	8,4
G-G-02	G-G	32,9	36,30	10,3
1-1-01	1-1	33,8	32,89	-2,7
1-1-02	1-1	34,5	34,35	-0,4

Table 1: Comparison of stress results in inspected locations.

In comparison with experimental test results is shown that results from FEM analysis are correct. An average difference was about 4%, therefore created FE model was validated and could be used for next analyses with modified geometry.

5 Location of concentrators

From FE model results were selected 5 regions with maximum tension stress levels, which were caused by high stress concentrations. For fatigue durability purposes stress values were indicated as Max Principal stresses.

Maximum stress peaks 46 MPa were in the lower tensioned flange near a rib between strain gauges in section F-F and G-G (see figure 2). Stress concentrations 140-180MPa were in region E in cut-out for main stringer and other important stress concentration was in holes for riveted nutplates. There will be rivets and nutplates installed in real undercarriage spar assembly, but for location of maximum stress peaks were used empty holes for rivets and nutplates.

6 Shape modifications

First shape modifications of 5 critical regions were designed and they were symmetrical for left and right side of spar. A comparison of original and modified spar geometry is shown in figure 6.

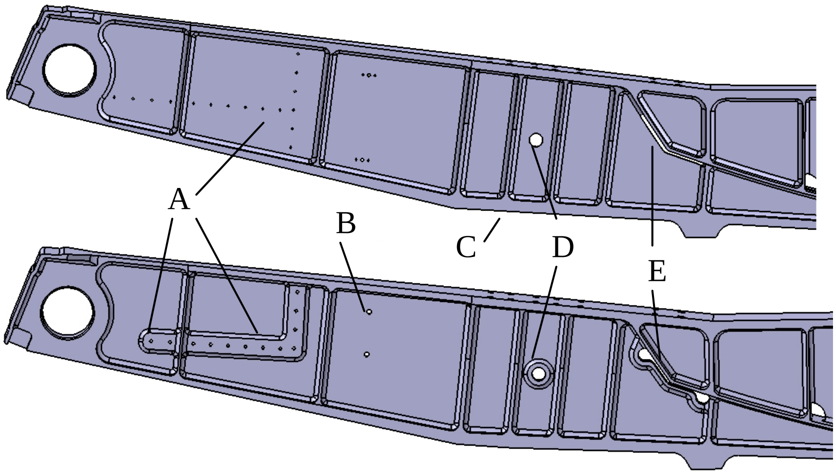

Figure 6: Detail of comparison of original and modified spar geometry.

Criterions for a complying were defined for a loading 10 kN and same for all inspected regions. Stress peaks on modified geometry must not to be higher than basic stress limit 45 MPa in locations without concentrations. And stress in concentrators (cut-outs, holes, radius, etc.) must be lower than 67 MPa (it means 1.5 times of basic stress limit).

Summary of maximum stress peaks indicated in particular regions and its decrease is presented in table 2.

Region	Description	Region stress peaks [MPa]	
		Original geometry	Modified geometry
A	Rivets for nacelles attachment	79, 73, 72	60, 49, 43
B	Riveted nutplates	87	40
C	Lower flange reinforcement	45	42
D	Technological hole	70	50
E	Cut-out for main stringer	178, 137	67, 63

Table 2: Summary of stress peak decreases in modified regions.

For every critical region are described final proper modifications in following subsections. Detail comparisons of the original and modified geometry are presented on figures 7 - 12.

6.1 REGION A - RIVETS FOR NACELLES ATTACHMENT

A proper shape modification in this region was an enlargement of rivet diameters in a spar web from diameter Ø 2,6mm to Ø 4mm. Simultaneously 4 margin rivets were removed, a new nacelle design and a local modification of a web thickness was made.

This increase of a spar weight was low price for large fatigue durability profit.

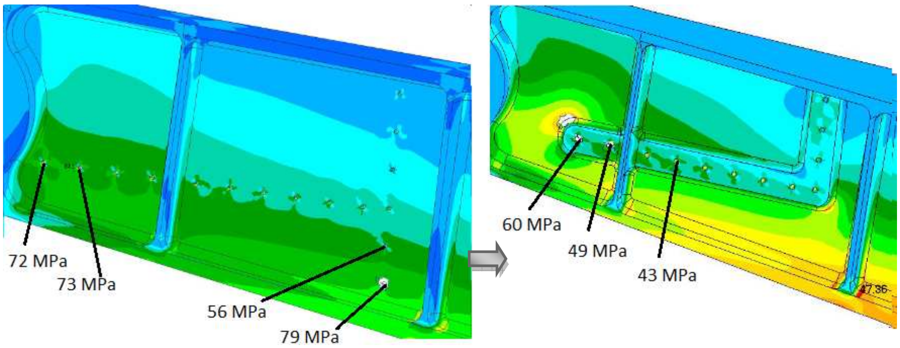

Figure 7: Region A - Stress peak decrease on rivets for nacelles attachment.

6.2 REGION B - RIVETED NUTPLATES

The best solution for this region was a substitution of nutplate type and a change of nutplate position to a place with a lower stress layer. A chosen rivetless nutplate could improve fatigue life due to its residual compressive stress on outer surface.

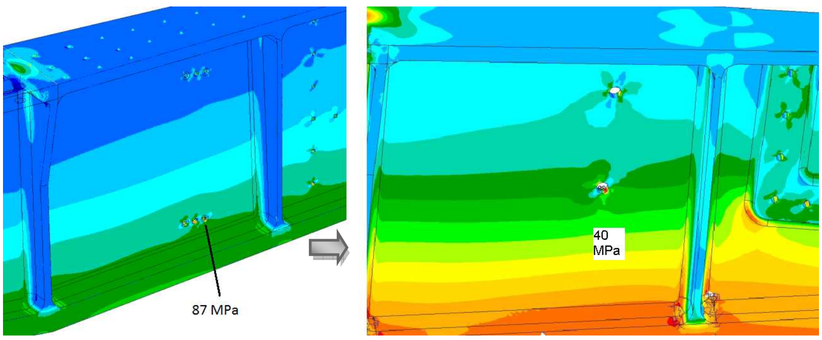

Figure 8: Region B - Stress peak decrease on nutplate and rivets.

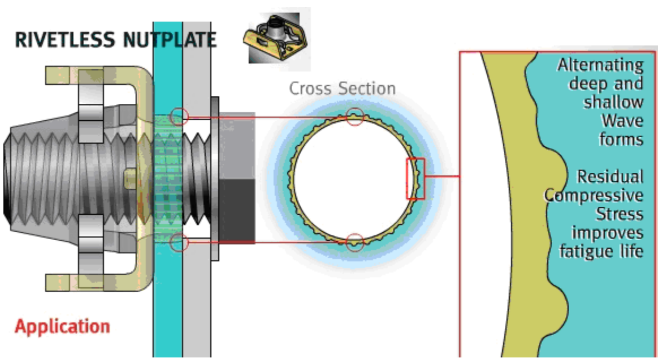

Figure 9: Region B - Substitution and position of nutplates.

6.3 REGION C - LOWER FLANGE REINFORCEMENT

The outer surface of the lower tensioned flange was reinforced with a thickness modification.

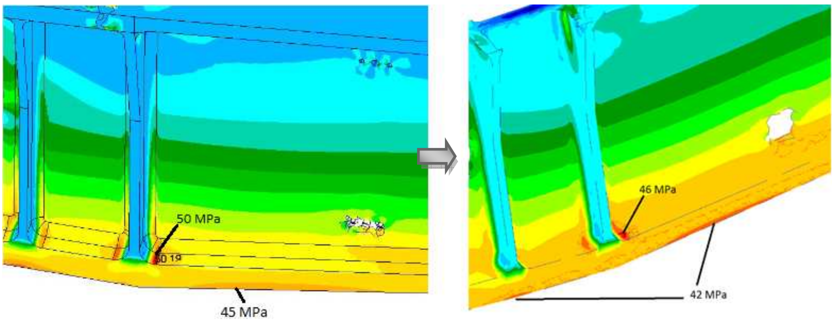

Figure 10: Region C - Stress peak decrease on external surface of lower flange.

6.4 REGION D - TECHNOLOGICAL HOLE

A circular web thickness modification was only one functional solution, which could decreased stress peaks around this technological hole.

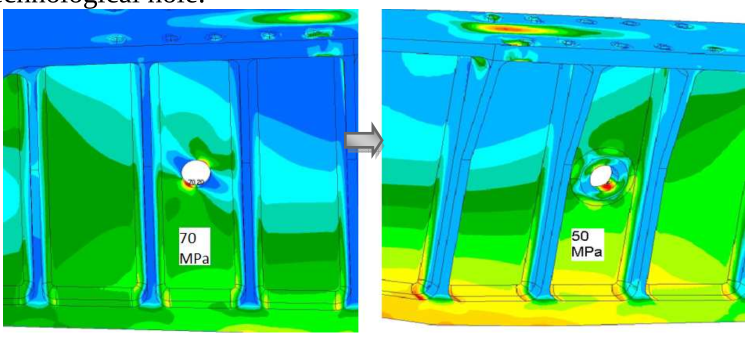

Figure 11: Region D - Stress peak decrease on technological holes.

6.5 REGION E - CUT-OUT FOR MAIN STRINGER

The most problematic region was cut-out in the web for main stringer. Many tested shape modifications were verified. A both side 3 mm thick enlargement around cut-out with a combination of holes on the ends was the final solution.

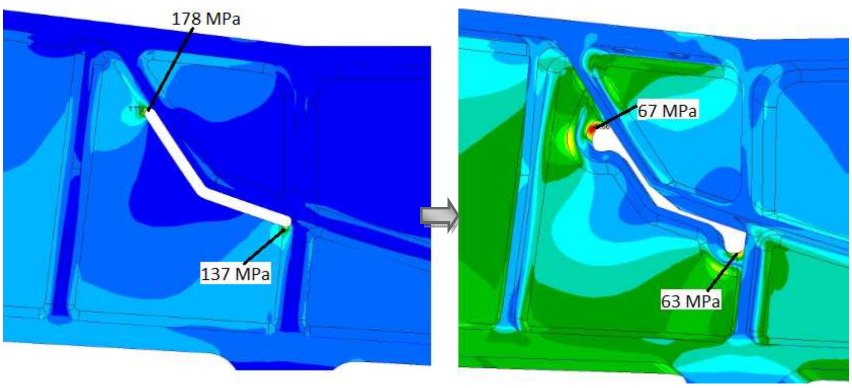

Figure 12: Region E - Stress peak decrease on cut-out for main stringer.

7 Conclusion

This article describes a geometrical optimization of main fuselage parts on the aircraft in CS-23 Commuter category according to fatigue durability, a stress analysis, a localization of stress concentrations and following geometrical modifications for a reduction and removing of stress peaks.

A shape optimization of undercarriage spar in frame no. 14 was divided into two essential parts.

A geometrically nonlinear analysis with contacts was made first. Then the FE model was validated with experimental test results and five main regions with the most critical concentrators was selected.

Next the repeated geometrical modifications and verifications of decrease of stress peaks could be applied. For an assessment of a proper shape modification a special criterion was used. Designed final geometrical modifications had decreased stress peaks below chosen limits and a fatigue durability of a critical fuselage spar was elongated.

Acknowledgment

This task was made under the terms of project MOSTA no. FR-TI2/557 "MOSTA - Modernization of Small Transport Aircraft to increase operation effectiveness and economy."

This project was realized with financial support from national budget of Ministry of industry and trade of Czech Republic.

References

[1] Katrňák, T., Plhal, M.: Geometrical Optimization of Main Spar in Frame no. 14, 2012,

Institute of Aerospace Engineering, report LU14-2012-410.ST

[2] CS-23, FAR 23 regulations

[3] MSC NASTRAN Handbook for nonlinear analysis, Version 67, 1992,
The MacNeal-Schwedler Corporation, Los Angeles, CA

[4] MSC NASTRAN Quick reference guide, Version 2008,
The MacNeal-Schwedler Corporation, Los Angeles, CA