6th International Conference
ðComputational Mechanics and Virtual Engineering ð
COMEC 2015
15-16 October 2015, Braşov, Romania

THE 3D LIGHTWEIGHT OPTIMIZATION FOR HIGH LOADED PARTS – CASE STUDY

Gabriel. D. Dima[1], Marius Diaconu[2], Ion Balcu [3], Ionuț Teșulă [4]
[1]Transylvania University, Brasov, ROMANIA, dumitru.dima@unitbv.ro
[2]NUARB Aerospace, Brasov, ROMANIA, m.diaconu@nuarb.ro
[3]Transylvania University, Brasov, ROMANIA, balcu@unitbv.ro
[4]Schaeffler, Brasov, ROMANIA, tesulinu@schaeffler.com

Abstract: *The 3D structural optimization is the most difficult optimization process, being used in aerospace industry only in few applications. In accordance with the efforts to set up a methodology to help to the implementation of extensive structural optimization in the development teams, within the paper a case study from a helicopter pilot seat is presented. The optimization of the fitting targeted lightweight, with respect to the constraints of a high loading environment and the manufacturing issues. Iterations of optimization, together with conclusions and lessons learned are presented.*

Keywords: *lightweight, topology optimization, aerospace, design for manufacturing*

1. INTRODUCTION

Aerospace structure and components have to comply with the major requirement of lightweight. This constraint emerged from the first aircrafts to fly and remains till nowadays on the spot. To comply with it, the manufacturers created internal lightweight methodologies and approach the design in an iterative process. Structural optimization may be also a solution, but its applicability is limited due to the resources involved vs. results. The objective of the paper is to present a case study of the structural optimization of a high loaded part, together with lessons learned and design recommendations.

2. TECHNICAL REQUIREMENTS

The lightweight allows to additional payload and/or extended range for an aircraft, therefore weight saving policies are close connected to the commercial issues as presented in [4], [5], [13].

Even the interest for the structural optimization can be reached since the 30's, due to calculation and manufacturing constraints, consistent results may be seen only after the 90's as published in [5], [6], [8], [3], [11]. These researches were focused on specific applications (parts or subassemblies) and not on working methodologies, this process being only at the beginning. The big manufacturers have no internal optimization methodologies, for specific applications just outsourcing work packages to the commercial solutions manufacturers or to R&D centers. Most of works are focused on case studies [3], or on methodology [2], [9], [10] reporting savings of 20 – 35%, within a time consuming and not very smooth optimization process. The stability, aero-elastic and manufacturing constraints are also critical, making the optimization process a multi-objective process [1], [6], [7].

This paper presents a machined part 3D optimization process, with a case study of a the floor attachment fitting of a helicopter crashworthy seat. The optimization results are post processed in three different designs to comply both with the manufacturing and the lightweight constraints.

As usual, the 3D structural optimization supposes an initial design, followed by a stress analysis as a start point to assess the optimization results. Structural optimization projects may be done on existing parts or to new developed parts. In the state of the art approach, after the design - stress iterations, the prototype is produced, tested, certified and released to operation. After the pre-serial production, up to three weight saving programs

may follow-up, or fatigue upgrades addressing the critical stressed parts. This programs (stretched as usual in 10 – 20 years) lead to the upgraded structure of an aircraft. This may not be considered as an optimization program, but an improvement which requires high skilled engineers, and previous aircraft lifecycle experience.
Structural optimization brings some advantages as: less design iterations and shorter time to market, better results taking into account numerical optimization commercial solutions existing on the market.

3. THE WORKING METHODOLOGY

Within this case study, the parts subjected to structural optimization were designed by an experienced designer and based on the state of the art solutions. The static FE analysis was performed to provide a reference for the optimization results (mass vs. stress and displacements). The optimization output was used for the part redesign according to the manufacturing constraints. Different designs were proposed to check the progress of the output parameters.
The loading conditions are according helicopter's certification regulations (FAR27) consisting on inertial load on different axis as follows ($g = 9.81\ m/s^2$):

- LC1 – FWD Crash, $N_X = -18.4g$
- LC2 – Down Crash, $N_Z = -30.0g$
- LC3 – Rear, $N_X = 1.5g$
- LC4 – Up, $N_Z = 8.0g$

For CAD design, the Catia V5R19 software was used, while for static stress analysis Hypermesh/ Radioss 10.0 was used. For topology optimization, the Hypermesh/ Optistruct 10.0 were used. The FE model consisted in 3D tetrahedral 2nd order elements, the mesh size being of 2.0 mm. The FE model of fiting was with all displacement restrainted in the screwing holes, and the loads applied in the hole containing the floor rails attachement pin.

4. THE INITIAL DESIGN

The case study refers to the floor panels attachment fittings of a helicopter crashworthy pilot seat (Fig. 1). The fittings are attaching the seat to the cockpit floor longerons below the plane of the honeycomb panels. The fittings are machined from aluminum alloy 2024T3, a very usual alloy used in aerospace structures.

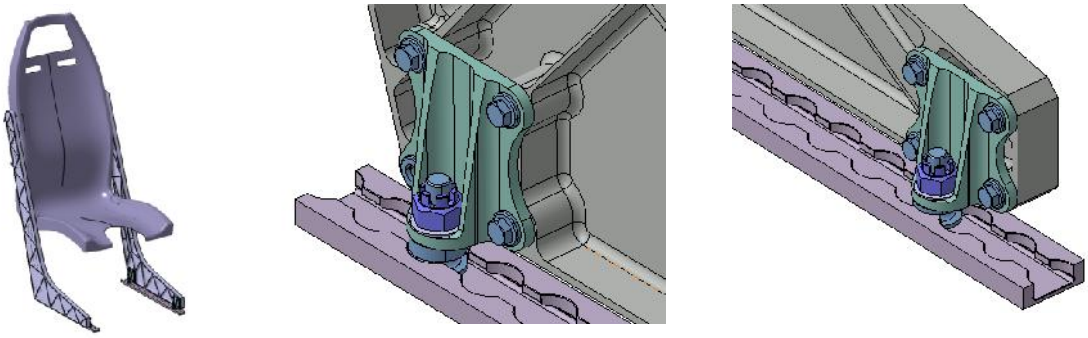

Figure 1: Isometric view of the crashworthy pilot seat and the attachment fittings

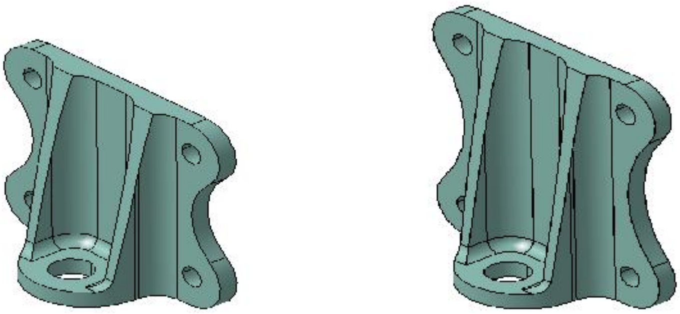

Figure 2: The front and rear attachment fittings

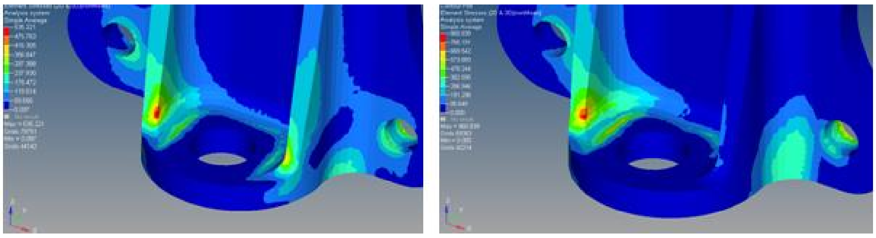

Figure 3: Front and rear attachment fitting – von Misses stress

The initial stress results of the fittings are indicated that the front attachment fitting presents higher von Misses loads (Fig. 2 and 3). Therefore, only the front fitting was considered for the optimization process, the rear fitting being redesigned according the output of the front fitting optimization process.

The results of the analysis of the initial design (Design start = DS) are shown in Table 1, the maximum von Misses stress being 863.7 MPa, displacement 0. 076 mm (load case 1, crash forward), for a part mass of 0.116 kg.

Table 1: The initial design results (DS)

Load Case	Stress [MPa]	Displacement [mm]
1. FWD	863,7	0,076
2. DOWN	361,4	0,032
3. REAR	145,7	0,013
4. UP	8,4	0,001

5. THE OPTIMIZATION RESULTS

The structural optimization consisted in a 3D topology optimization using the Optistruct 10.0 commercial solution. The optimization method consisted in choosing a volume with the permissible limits and defining the mounting points and force application, using a stress parameter and weight parameter; the constraints for these parameters was less then the initial values (700 MPa and 0.105Kg, respectively).

The optimization output consisted in a shape linking the load application area with the mounting holes areas.

The shape is organic, without the possibility of manufacturing with the existing state of the art technology (Fig. 4). Even the additive manufacturing technology may be suitable, a certified technology for aerospace industry had to be selected – the multi axis machining. The resulted design followed the output shape, taking into account the machining constraints (generation of surfaces, basement, corner and base radius, etc). Because the mass was 0.101 kg, further designs were generated to decrease the mass.

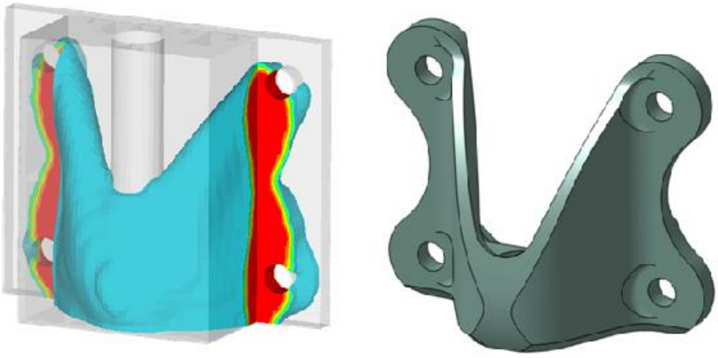

Figure 4: The optimization result and the design D00

The design D01 was developed on the basis of the design D00. The inner cutout geometry and the curved central V - shaped edge were simplified, together with a consistent weight saving of 20%. The design D02 was based on idea that the load application area should consist of two levels in order to decrease the stresses due to the moment loads. The design is more robust, but the mass increased with 10% relative to the design D01.

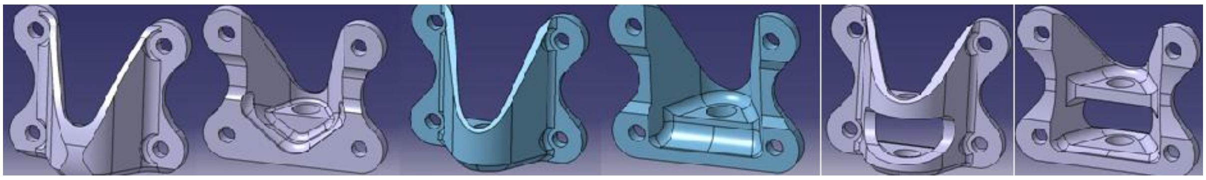

Figure 5: The design iterations D00, D01 and D02

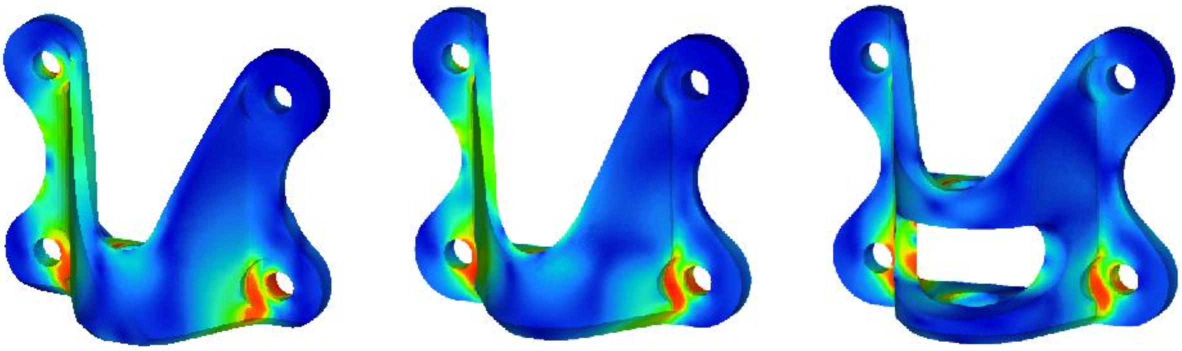

Figure 6: The von Misses stress distribution of the design iterations D00, D01 and D02

6. RESULTS AND DISCUSSIONS

The optimization output passed through a redesign process to allow machining of the resulted shape. The design D00 was the first design iteration to comply with the manufacturing constraints. As per graphs from figures 7 and 8, the design D00 presents a major stress reduction (about 50%) for a double rigidity than the initial design (DS). Taking into account the weight saving, the progress from variant DS to D00 is significant.

For the design D01, the stresses are higher for a small variation of rigidity, together with a consistent improvement of the machineability. Taking into consideration the 20% of weight reduction, this variant may be considered for further product development. The design D02, comes up with a von Misses stress growth for a 10% weight saving and the same machineability as D01. Due to the high values of the von Misses stress, this variant was not developed anymore.

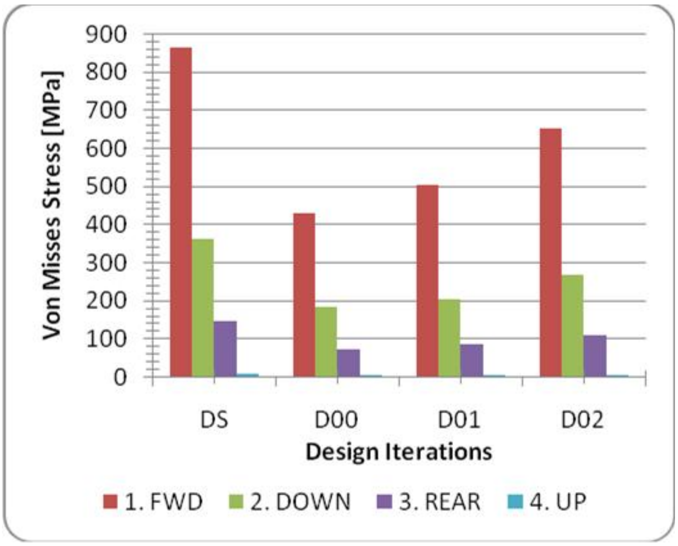

Figure 7: Maximum von Misses stress of the design iterations

The parameters of the fitting may be further adjusted depending of the parameter with the highest importance. Thus, if there is not a target for weight, by increasing the wall thickness/ decreasing fillet radii the stress level in hot spot stress areas may be decreased to a level required by the ultimate tensile stress of the material. Thus, a consistent weight saving may be obtained by changing material form steel to titanium or from titanium to aluminum. If the stress level is a target, then, the part will be refined by design/ stress iterations until the von Misses stress is near below the target, resulting the mass and the displacement.

Even the optimization process represents a step forward in the design process, an additional process of adjustment of the geometrical parameters may offer the final configuration of the part.

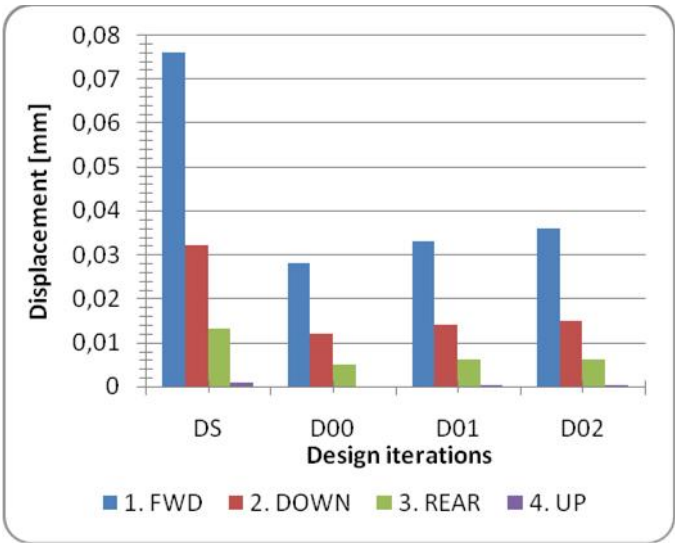

Figure 8: Maximum displacement of the design iterations

7. CONCLUSIONS

Within the paper a case study of structural optimization of a high loaded part was presented. After the stress and displacement assessment of the initial design, a 3D topology optimization was made using a commercial numerical solution. Based on the optimization output, three design variants were proposed. Using the static stress analysis, the new designs were assessed in order to select the best combination of the output parameters.

Based on the whole process results, the following conclusions may be formulated:

- only the critical load case/ cases have to be considered for the static stress/ displacement assessment, the approach being conservative;
- the output of the optimization process needs redesign by an experienced designer;
- the best results may be obtained by proposing few design to comply with the manufacturing constraints;
- finding the best configuration of the strength/ rigidity/ weight and machineability is not a linear process (the lowest stress were obtained for the first design iteration);
- the optimization process is multidisciplinary and there is no any available methodology to get a result to comply with both strength and machineability requirements.

Future investigations are worth to be done in the area of compliance with other requirements as maintainability and inspectability, considering also new manufacturing techniques as additive manufacturing.

REFERENCES

[1] Brackett D, Ashcroft I, Hague R. Topology optimization for additive manufacturing, Loughborough, Leicestershire, 2011

[2] Dima G., Balcu I., Zamfir M., Method for lightweight optimization for aerospace milled parts – case study for a helicopter pilot lightweight crashworthy seat side struts, 8th International Conference Interdisciplinarity in Engineering, INTER-ENG Proceedings, Tirgu-Mures 2014

[3] Gubisch M. New Lufthansa seat saves nearly 30% in weight, Flightglobal, Dec 2010, www.flightglobal.com

[4] Hertel H. Leichtbau., Bauelemente, Bemessungen und Konstructionen von Flugzeugen und anderen Leichtbauwerken, Springer, New York, 1980

[5] Kaufmann M. Cost/ Weight Optimization of Aircraft Structures, KTH School of Engineering Sciences, Stockholm, 2008

[6] Krog L, Tucker A, Rollema G. Application of Topology, Sizing and Shape Optimization Methods to Optimal design of Aircraft Components, Airbus UK Ltd, 2002,Bristol

[7] Maute K, Allen M. Conceptual design of aero-elastic structures by topology optimization, Structural and Multidisciplinary Optimization, vol.27, no.1-2, pp. 27 – 42, 2004

[8] Schuhmacher G. Optimizing Aircraft Structures, Concept to Reality, Altair Engineering, 2006.

[9] Teşulă I., Balcu I., Dima G., The Lightweight Optimization of a Composite Shell – Case Study of a Helicopter Crashworthy Seat , Advanced Composites Materials Engineering COMAT Proceedings, pp. 36-46, Derc Publishing House, USA, 2014

[10] Yancey R. Optimization and Modelling Technologies, Altair Engineering, 2006

[11] Wang Q, Liu Z., Gea H., New topology optimization method for wing leading-edge rib, Journal of Aircraft,vol.48, no. 5, 2011

[12] * * *, JAR/ FAR Part 27 – Airworthiness Standard: Normal category rotorcraft, Federal Aviation Administration, 2013

[13] * * *, “What’s a few pounds here and there?”, International Conference Innovative Aircraft Seating Proceedings, Hamburg, 2011