

DEVELOPMENT AND APPLICATION OF A NEW DESIGN TOOL FOR AEROSPACE STRUCTURES

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Keywords: *Optimization, design tool, aerospace structures, postbuckling*

Abstract

European aircraft industry demands for reduced development and operating costs, by 20% and 50% in the short and long term, respectively. The 3-year project Globales Tragverhalten (Global Structural Behaviour), which was finished 2003, contributed to this aim by reducing structural weight at safe design; it exploits considerable reserves in fuselage structures by taking the knowledge of the redistribution of internal structural loads into account. The Institute of Composite Structures and Adaptive Systems of DLR developed in that project in co-operation with Airbus Germany a new design tool for lightweight aerospace structures. This design tool has the capability to reduce structural weight automatically and was applied on one Airbus-A340 section. This paper explains the optimization concept of the design tool and gives some project results.

1 Introduction

The partners Airbus Germany, Institute of Composite Structures and Adaptive Systems (DLR), Institute of light weight structures (University RWTH) Aachen and the Institute of light weight structures (University Braunschweig) participated in the German research project “Globales Tragverhalten (Global structural behaviour)”. They developed new concepts, methods and tools which allow a

better understanding of the global structural behaviour of the aerospace structures and which also allow to reduce structural weight. DLR participated in the following two tasks:

1. Investigations of aerospace panels
2. Development and application of a new design tool.

In the first task the structural behaviour up to collapse of different panels which are parts of one Airbus A340 section was investigated using the commercial software ABAQUS/Standard. The influence of different parameters was studied and the computations were validated by tests which were also performed in that project. Selected results of that task were published in [1]. This paper concentrates on the results of the second task.

The development of the new design tool in the second task followed two objectives. Firstly, the influence on the load redistributions due to changing of local parts of the structure should be investigated. Based on the results improved design rules should be derived. Secondly, these design rules should be included into the design tool in order to improve the design process to reduce structural weight. All investigations were performed for the 5 most critical load cases on one section of an Airbus 340.

2 Structure and load cases

The new design had to be developed for the optimization of typical Airbus airframe sections. Figure 1 illustrates a possible finite element model on an Airbus A340 fuselage. It illustrates also the corresponding discretization of one fuselage section and a panel which is part of that a section.

Figure 2 shows the section of the A340 which was considered for all investigations of the load redistributions and also the optimization. For the optimization of that section only the skin and the stringers below the windows of the middle part (cf. Figure 3) were considered.

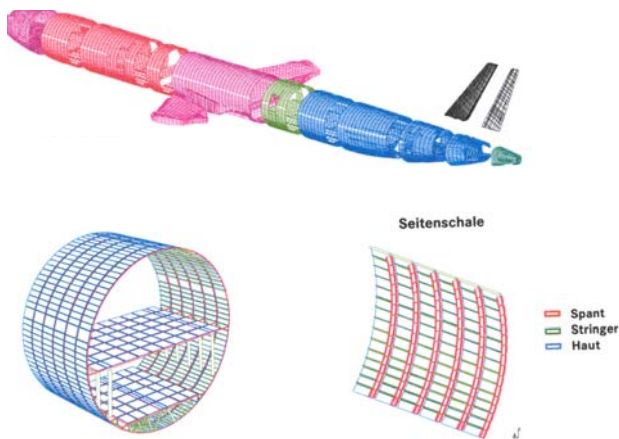


Fig. 1. A possible finite element model of an A340

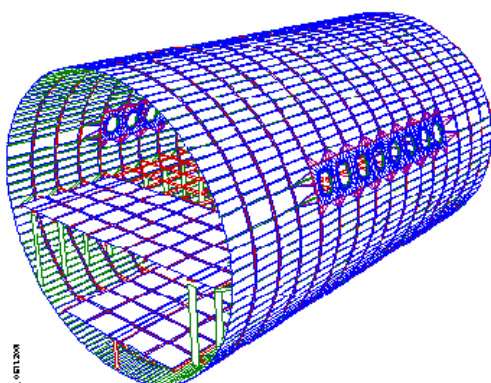


Fig. 2. Section considered for the investigations and optimization

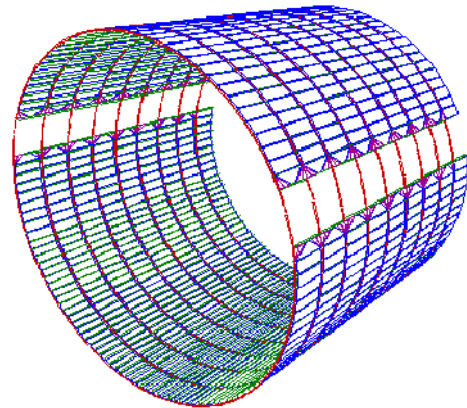


Fig. 3. Part of the section investigated which was optimized

All investigations were performed for the 5 most critical load cases on one section of an Airbus 340. The loads are combinations of axial compression, shear and bending as visualized in Figure 4. For these load cases the partner Airbus performed also barrel tests which build the basis for the validation of the numerical results.

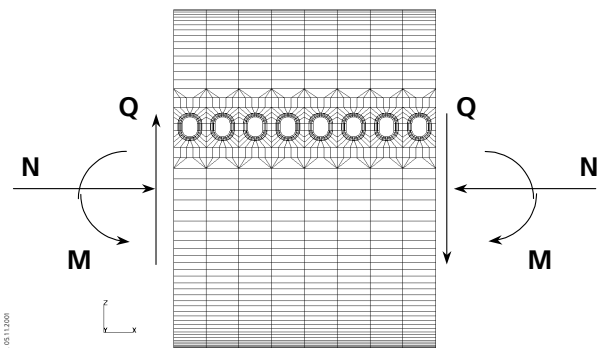


Fig. 4. The critical load cases are combined loads of axial compression, shear and bending.

3 Software ISSY

The new design tool had to be combined or linked with the Airbus-in-house tool ISSY. The acronym ISSY stands for **I**ntegrated **S**tructure **M**echanical **S**ystem. It is a modular structured program system, which is utilized for various computations of aerospace structures. Different tools are integrated under a common data basis and a common user interface. The actual finite element calculation is performed in ISSY

linearly by the call of the commercial software tool NASTRAN. In combination with NASTRAN ISSY has the following 4 tasks:

1. Improved pre-processor. It generates NASTRAN-Input files for typical aerospace structures much more easily.
2. Specified post-processor, NASTRAN can be read directly in ISSY
3. Certification tools. Based on the NASTRAN results ISSY calculates all additional calculations (skin buckling, Johnson-Euler-Buckling, Forced Crippling, etc.) automatically.
4. Quasi non-linear calculation: ISSY simulates the nonlinear structural behaviour in that way, that after each iteration skin-stiffnesses are reduced according the effective widths (cf. Figure 5). This convergence is very fast, only after a few iteration a stable solution is reached (cf. Figure 6).

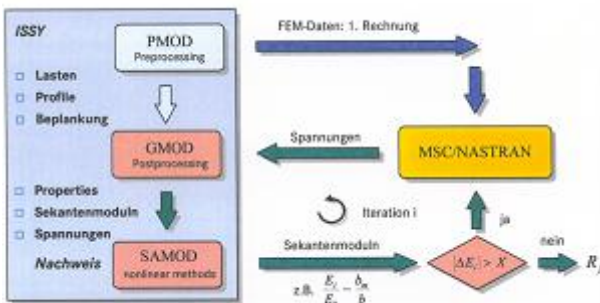


Fig. 5. Quasi non-linear calculation in ISSY

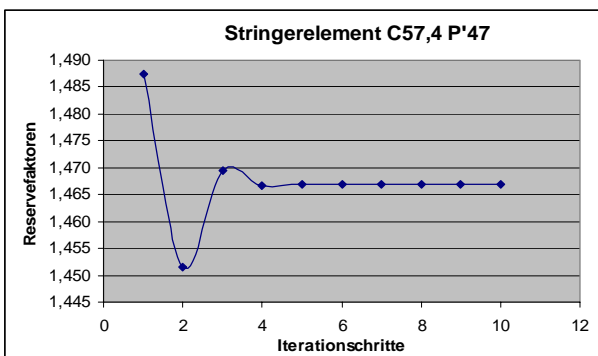


Fig. 6. Convergence study within ISSY on an example of a stringer element

3 Investigation of load redistributions

The objective of that task was to get a better understanding of the global load redistributions due to changing of local parts of the structure. Based on the results improved design rules should be derived. This new knowledge obtained is important for design engineers because the aerospace structures are usually statically overestimated and it is therefore difficult to predict the structural behaviour in advance, especially in the post-buckling region.

3.1 General results

In the first part extensive studies were performed in order to investigate the load redistributions due to changing of the skin thickness or the type of stringer in a local part of the structure. The change of the reserve factors was considered as criterion for the change of the structural behaviour. Different aspects were investigated and the outcome was the following:

- It was checked whether the number or the arrangement of the modified elements has a significant influence on the kind of the load redistribution. The result was that the first failure observed was almost independent of the kind of element group.
- The structural modifications have only significant influence in the local surroundings of the changed area. The change of reserve factors on elements, which are more far away, is negligible.
- In general, the failure mode did not change in areas considered.

3.2 Rule identified

For certain areas of 3 symmetrical load cases a similar structural behaviour was observed. For that case a new design rule was derived (cf. Figure 7). It can be seen that the reserve factors of the surrounded elements of the modified element change their structural behaviour usually in the same manner.

This behaviour is plausible and can be interpreted with coupled spring connections. One must assume that each skin element is replaced by a spring. In longitudinal direction the springs are connected in parallel and in transverse direction in serial. The rule (assumption: increase of the skin thickness) can be explained in the following:

- 1) The reserve factor of the strengthened element must be larger because this element is now overdesigned
- 2) The strengthened element pulls larger loads. The adjoining elements in longitudinal direction have the same internal force, because the loads are in springs connected in serial constant. Their reserve factor must therefore be

smaller because these elements were not strengthened.

- 3) The adjoining elements in transverse direction are connected with the strengthened element in parallel. Their internal loads must therefore be smaller (and the reserve factor larger) because the sum of the loads of springs connected in parallel is constant and the strengthened element has a larger internal load.

This rule was implemented in the design tool (cf. next section). The application of that rule decreases the optimisation time of the design tool up to 25%.

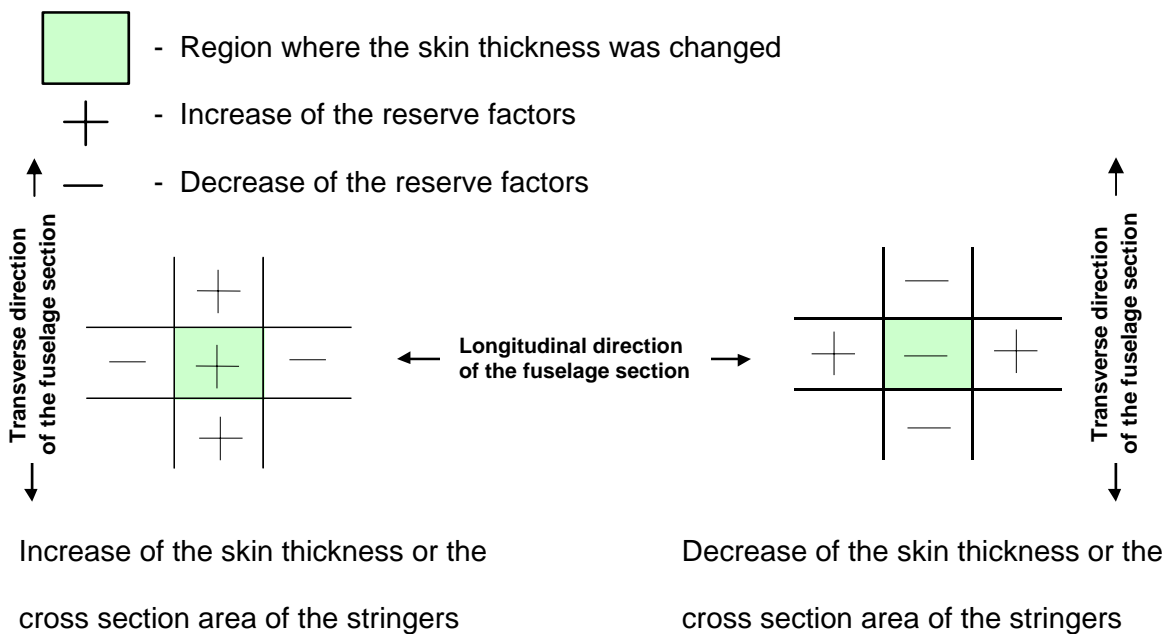


Fig. 7. Sensitivity study – Rule identified

4 Design tool

The objective of the design tool developed is to reduce weight of typical Airbus aerospace structures. The tool optimizes the skin thickness and the type of stringer of one Airbus A340

section for any number of load cases. It is embedded in the commercial software MSC/Nastran and the Airbus software ISSY (Integrated Structure Mechanical System). The full automatically design process considers only the skin and stringers with the objective to reduce structural weight of a fuselage section.

The design tool selects the skin and stringer elements with the highest reserve factors and reduces their thickness by a given value. The design rule identified in the first project part (cf. previous section) was also taken into account and could reduce the optimization time. The design tool was developed for a certain section of the A340, however, it allows an easy extension to other sections of the A340 or other airbuses as well.

4.1 Conventional optimization procedure

The concept of the optimization procedure is illustrated in Figure 8. Before the start the following design parameters must be defined:

- Reduction factor for the skin
- Minimal required skin thickness
- Minimal allowed reserve factor (e.g. 1.0)
- What shall be optimized
 - Skin
 - Stringers
- Maximal number of iterations in ISSY
- Maximal number of iterations in the design tool
- Number of load cases
- Continuation of a previous computation
- Conventional or improved optimization

Then the procedure starts in a first step with a normal computation of the structure by means of ISSY and NASTRAN. At the end the design tool reads all reserve factors, it chooses this element with the largest one and decreases the thickness of the skin or the cross sectional area of the stringer. It will be also checked if the element found is in a certain where the design rule (cf. section 3) can be applied. In that case also the geometry of the 2 adjoining elements in longitudinal direction will be reduced. This increases the optimization process up to 25%. For the optimization of the stringers there is one slight difference. The stringers must be panel wise the same. So if the stringer element with the largest reserve factor is found, the stringer type of the whole panel (part of the section) will be changed. After the modification of the skin or stringers the computation of the structure using NASTRAN and ISSY is repeated. The

reserve factors of all elements are read again and the procedure as described above will be repeated. However, there is also one additional step. From that iteration it can happen that due to the load redistribution of the changed geometry the reserve factor of some other elements are smaller than the minimal allowed value. In that case the thickness of the skin or the cross sectional area of the stringer of all these elements is increased. After some hundred iterations the optimization is running to an optimized structure with a reduced weight.

4.2 Fast optimization procedure

The optimization described in Section 4.1 shows a good convergence, however, the disadvantage is that only one element per iteration can be modified. Due to this reason up to 2000 iterations are required in order to get the optimized solution. The optimization procedure can be accelerated significantly by the following trick. At the beginning of the optimization the thickness of all skin elements and the cross sectional area of all stringers is set to minimal required value. After the first calculation the design tool founds of course out that the reserve factors of the most elements are too small. However, the advantage is that now not only one element is modified but a large number of elements. The structure is now running to the optimized solution from a smaller start weight, but significantly faster (at least factor 50).

5 Application of the design tool

The design tool was applied on one section of the Airbus 340. The objective was on the one hand to check the applicability and on the other hand to find out how much weight could have been saved on an already designed aerospace fuselage. This design tool can be applied to number of load cases which is not limited. In that study presented the tool was in a first step applied to only one critical load case. In a second step to the tool was applied to the 4 most critical load cases. In each case the tool was as

first step applied to optimize the skin and in the second step to optimize the stringers.

5.1 Application to one critical load case

In a first step the design tool was applied to one critical load case only in order to check the applicability and the influence of some parameters. Figure 9 illustrates the skin weight over the number of iterations for different parameters. The calculations were performed for the conventional optimizations using 3 different parameters of the skin reduction factor and one fast optimization. It can be seen that the larger the reduction factor the faster the solution converges. However, the calculation using the smaller reduction factor allows reaching a smaller optimized weight due to the finer optimization. The application of the fast optimization tool converges very fast, even using the small reduction factor of 10%. This method is at least 50 times faster than the conventional optimization. The result of that optimization for that one load case was that the skin weight could be reduced for 17.8 %. Based on that solution the calculation was applied again to optimize the stringers. The result is a weight reduction of 5.9%.

5.2 Application to the 4 most critical load cases

In a second step the design tool was applied to the 4 most critical load cases. Similar as Figure 9, Figure 10 illustrates the skin weight over the number of iterations for different parameters. The calculations were performed for the conventional optimizations with and without application the rule identified and one fast optimization. It can be seen that application of the rule accelerates the computation time up 10%. However, the computation using the fast optimization is again very fast here. It reaches after only 25 iterations the optimized skin weight which is 14.8% lighter in comparison to the original one. Based on that solution the calculation was applied again to optimize the stringers. The result is a weight reduction of

5.9%. It must be noted that the application of the design tool for all number of load cases would probably lead to a smaller weight reduction of skin and stringer. However, because the 4 load cases considered are the most critical ones, it can be assumed that the real optimized weight is very close to the obtained one.

5.3 Interpretation of the results

Figure 11 shows the comparison of the skin thicknesses before and after the optimization for the 4 critical load cases. The figure shows one half of the lower section part. It can be seen that after the optimization large parts of the skin have the minimal required thickness of 1.6 mm. On the other hand there are small strips in longitudinal direction which are thicker than before. If one has a closer look one will find out that these small strip regions are exactly at the crossings of the panel parts of the section. At these positions the stringers are much stiffer than at the other parts. This explains the more thicker skin elements in that area because the stiffer stringers pull more forces which have also to be carried by the corresponding skin. The optimized structure is comparable to a framework. This behaviour is plausible.

It must be noted that the original sections contains regions which are constructive reinforced. In that optimization process presented here it was allowed to skip the reinforcement in that regions in order to demonstrate the framework analogy. In all other calculations these reinforced regions were of course kept unchanged.

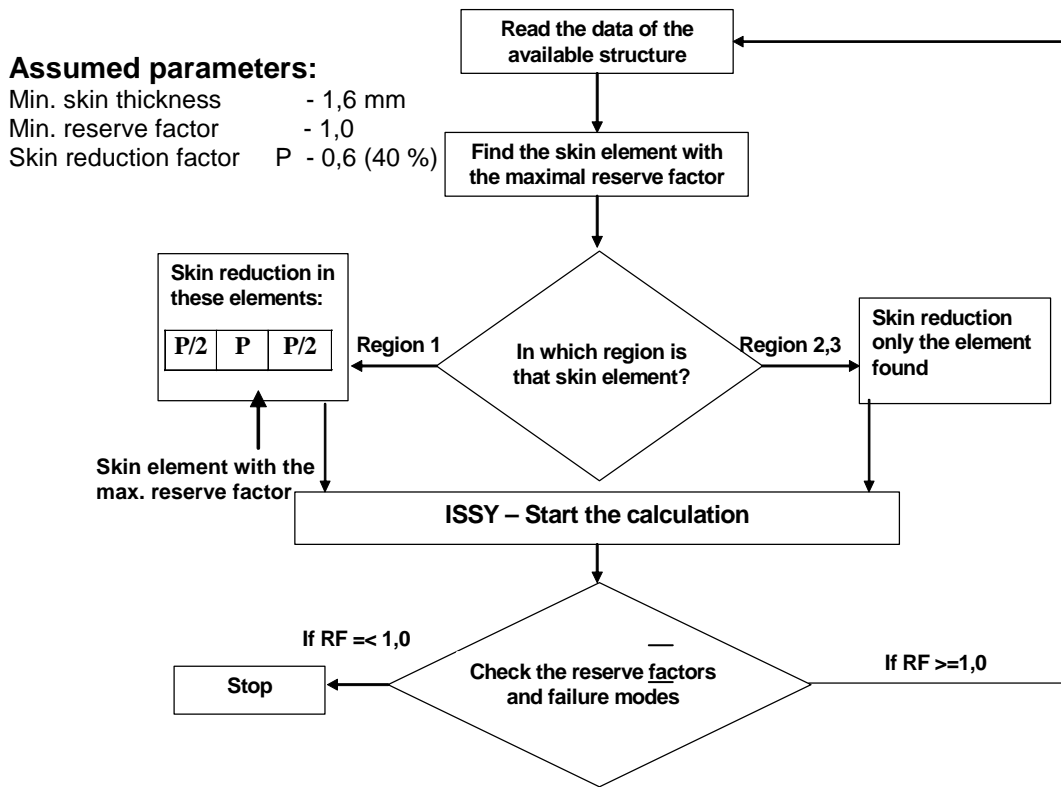


Fig. 8. Optimization procedure within the design tool

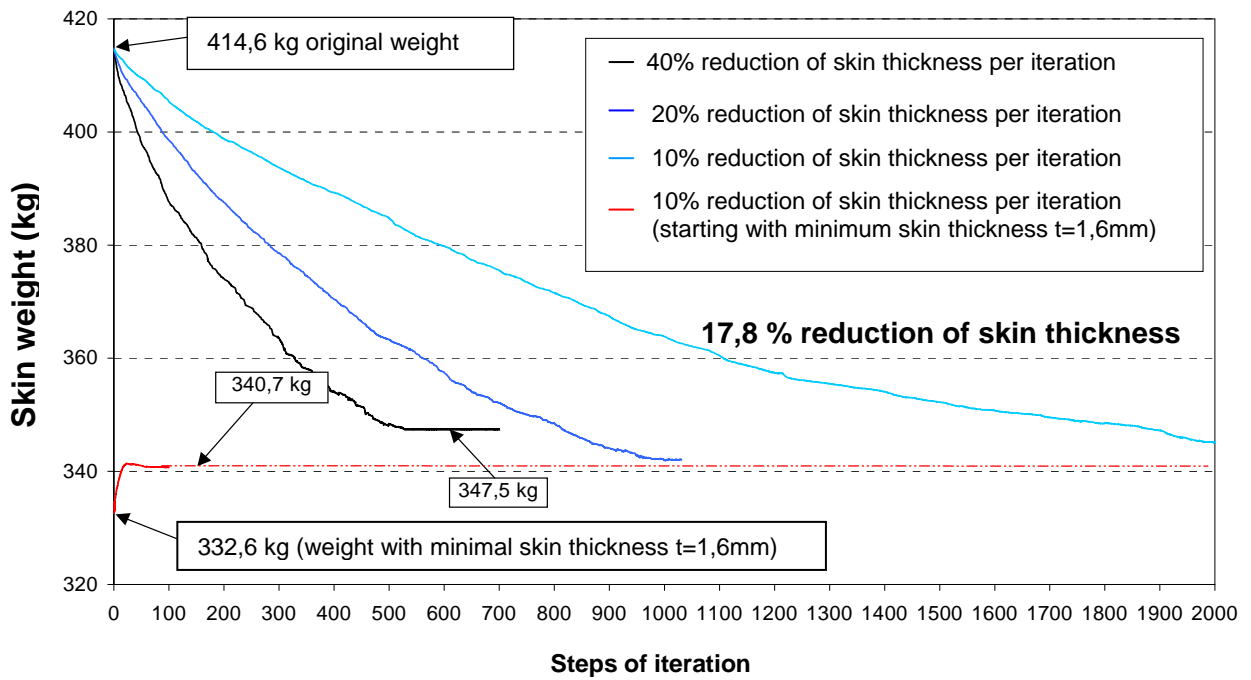


Fig. 9. Optimization skin thickness for 1 critical load case

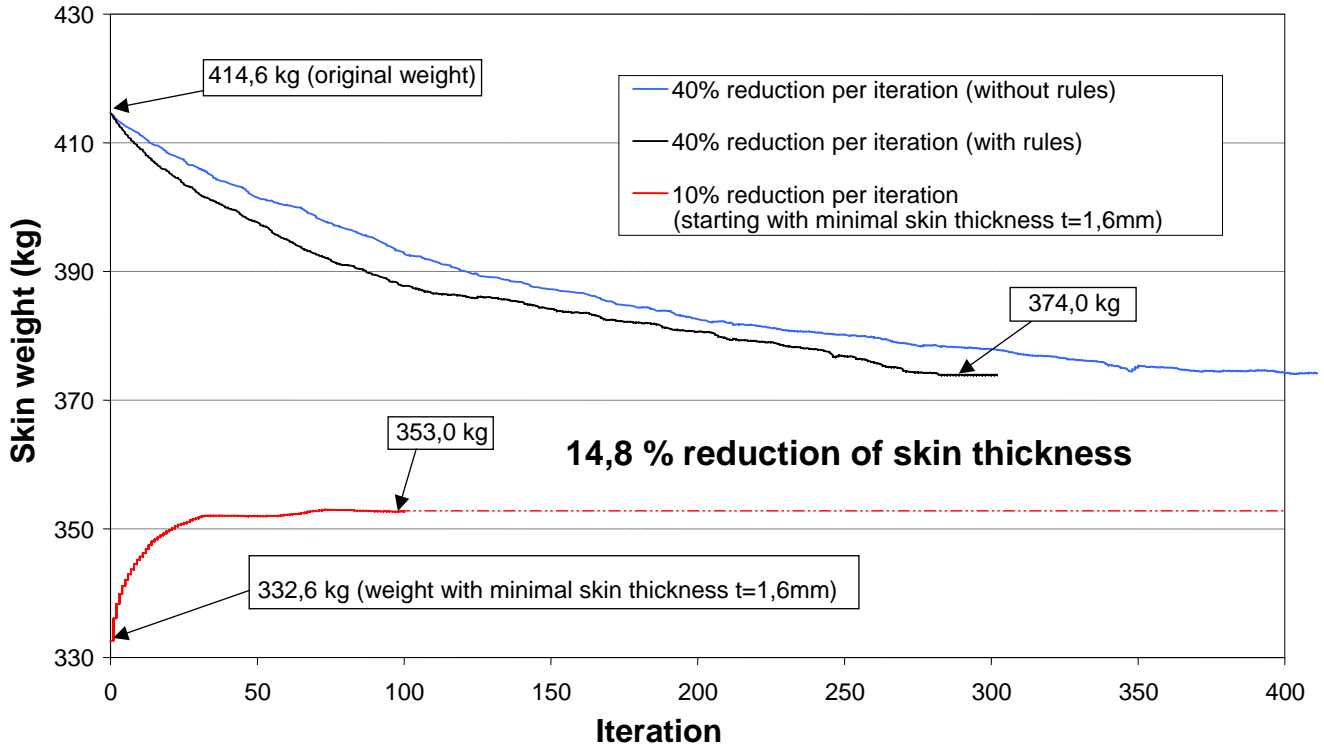


Fig. 10. Optimization of the skin thickness for 4 critical load cases

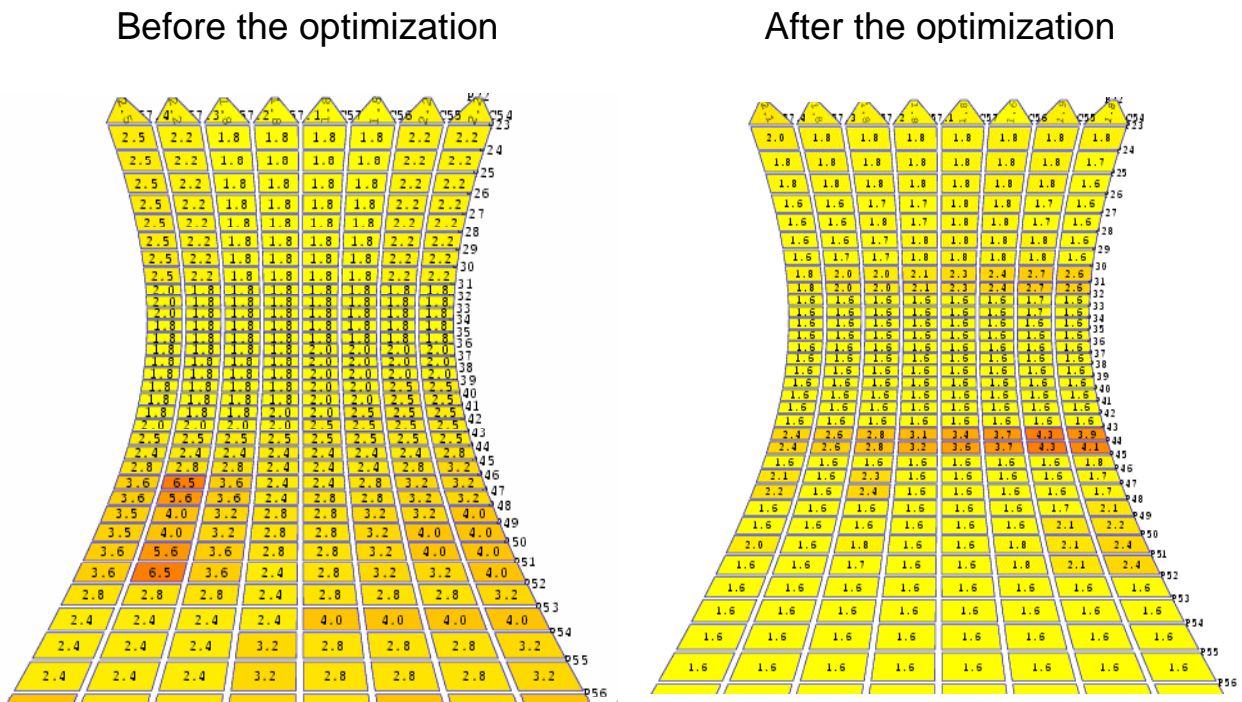


Fig. 11. Skin thickness of one Airbus-A340 section before and after the optimization

7 Airbus comments to the optimized structure

AIRBUS Germany has the following comments to the results obtained by the new design tool:

1. For all calculations homogenous boundary conditions were assumed (demand by Airbus). In the real fuselage the section investigated connects to the centre section which has a larger stiffness influence of the cotter carriers. Due to this reason some parts of the lower section are reinforced.
2. Load case changes (reduction), which are recognised after the certification could not be taken into account any more.
3. The today's certification tools are less conservative than the former used for the A340.

8 Acknowledgements

The project *Globales Tragverhalten* was supported by BMBF (German Federal Ministry of Education and Research) and Airbus Germany. All support is gratefully acknowledged.

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