Case Study

Eco Design and Optimization of a Truck Suspension Arm

Developed and curated by the Ansys Academic Development Team

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Ansys Software Used

This resource uses Ansys Granta EduPack™, a teaching software for materials education, Ansys Discovery™, a 3D product simulation software, and Ansys optiSLang®, a process integration and design optimization software.

Summary

In modern engineering, it is expected to embed sustainability impact of products as constraints or even objectives in the design process to contribute to company's Environmental, Social, Governance commitments or to comply with regional policies. While climate change CO_2eq and energy consumption over the whole life cycle of a product reflect only a portion of the environmental impact of a product one would expect from life cycle inventory, they serve as reasonable proxies for engineers and designers to use as parameters to improve their designs and minimize impact using an optimization approach. This case study addresses the re-design of a truck suspension arm component using smart combination of material and geometry parameters, with the aim to reduce overall carbon emissions while making sure functionality and safety concerns are addressed. It consists in carrying out materials selection, geometry changes, Finite Element Analysis (FEA) and optimization approaches to identify re-design options. In a final trade off analysis, several scenarios are explored, including their eco-assessment across the whole life cycle of a product. This enables us to discuss additional considerations to critically assess and improve the design recommendations.

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1. Introduction

1.1 Background & Methodology

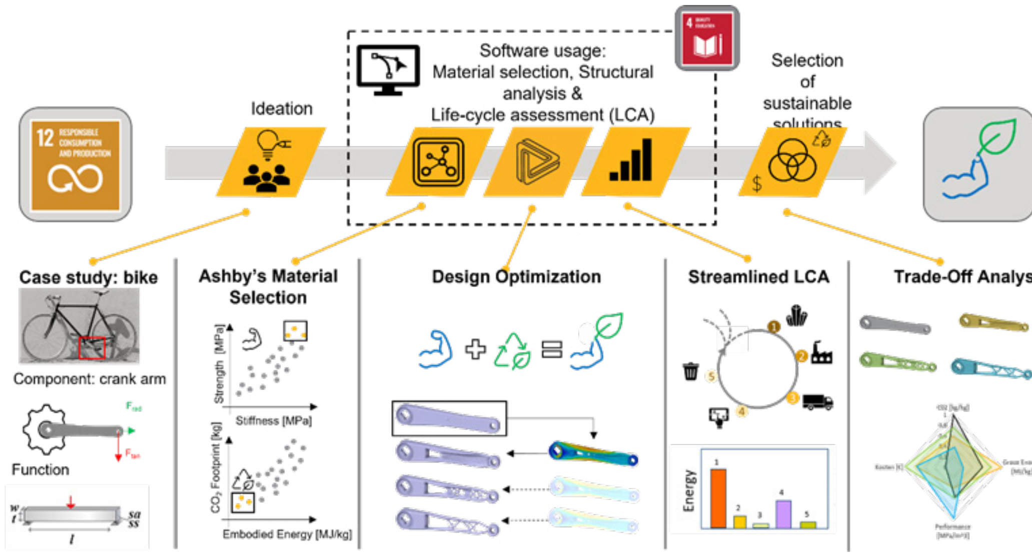

Figure 1 schematic of the design methodology used in this case study[1]

Figure 1 illustrates the approach used in this case study to solve a multi-faceted product design problem, where material and design are considered concurrently, while including a simplified LCA and trade-off analysis as an integral part of the process. It includes the following steps:

1. Ideation: Define the problem and its function, objective, and constraints.
2. Strategic material selection: Employ the Ashby methodology embedded in the Ansys Granta EduPack software.
3. Structural Analysis/Optimization: Optimize the geometric parameters combining Ansys Discovery multi-physics simulation software and Ansys optiSLang process integration & design optimization software
4. Streamlined life-cycle-assessment: Utilize the Eco Audit tool within Granta EduPack software based on materials and design choices made in Steps 2 and 3.
5. Trade-off analysis: Elucidate and critically assess the mechanical, ecological and economic performance of different materials + geometry combinations and discuss additional considerations that could affect the decision-making process during the product design stages.

The method to achieve steps 2 and 3 are depicted in Figure 2. Material selection depends on defining rigorously function, constraints and objectives of the design requirements. Structural analysis is the succession of design set up, pre-processing, simulation method selection, results post-processing and validation.

1 You can find another example of implementing this methodology in the Bike Crank Design Optimization – Towards Sustainable Product Design Case Study.

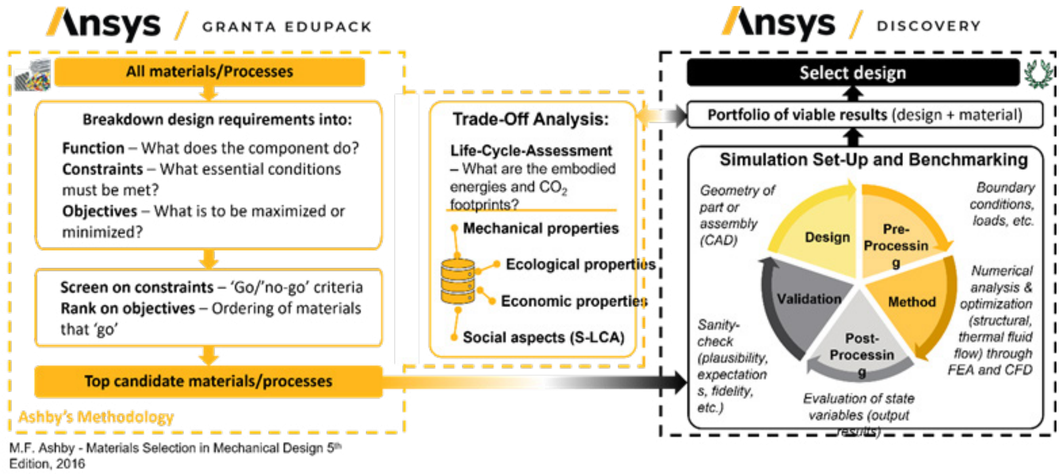

Figure 2. Workflow of the iterative design steps combining materials selection, design geometry change, structural analysis and environmental assessment[2]

If you are new to the above-mentioned software, the (self-) learning resources summarized in Table 1 are recommended and should serve as an introduction to key functionalities and tools employed in this case study.

Table 1. Software, functionalities and corresponding links to learn more about the tools used

Software	Relevant Functionalities/ Tools	Links
Ansys Granta EduPack	Materials Selection	Basic Systematic Materials Selection Ansys Innovation Course
		Advanced Materials Selection using Ansys Granta EduPack Ansys Innovation Course
	Eco Audit Tool	Introducing the Eco Audit Tool in Ansys Granta EduPack Tutorial
Ansys Discovery	Structural Analysis	Structural Simulation using Ansys Discovery Innovation Course
Ansys optiSLang	General/getting started	Parametric Analysis and Optimization using Ansys optiSLang Innovation Course

1.2 Problem statement

The focus of the study will be on the realistic scenario of improving a structural component in a truck suspension assembly from an eco-design standpoint for a new series production. With existing reference material and design geometry as a starting point, we will look to (i) find suitable material alternatives which fulfill design requirements and could reduce part mass and/or improve mechanical

2 More information about this Sustainable Product Design Methodology can be found in a lecture presentation here.

performance (ii) using selected material candidates, identify best trade-off between displacement and mass of the component by varying geometric parameters and monitoring predicted behavior with structural finite element analysis as well as (iii) compare three final candidates in a streamlined Life cycle analysis to discuss CO_2eq impact of the product over its life scenario.

2. Design definition and material selection

2.1. Reference material and design

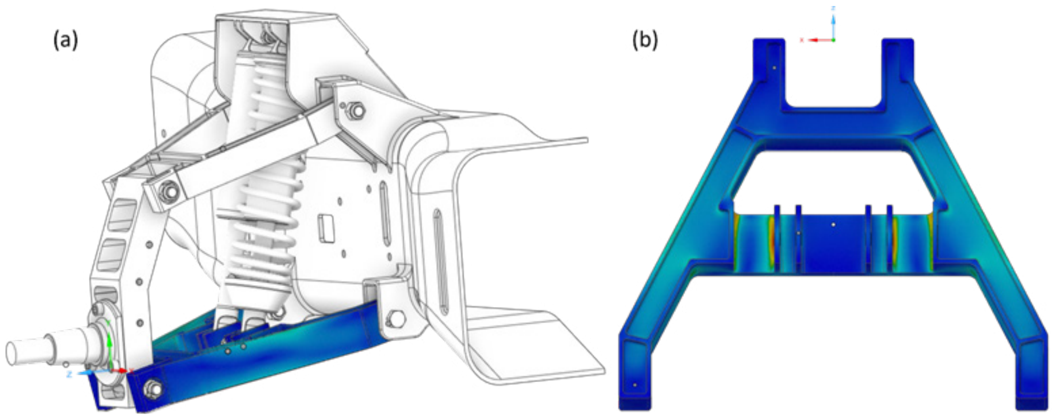

Figure 3. CAD view of (a) the full truck suspension assembly on the left
(b) the lower arm re-designed in this study on the right

Figure 3(a) shows our truck suspension assembly. We will limit the study to the lower arm component, which is fixed on one end, and under loading on the other (Figure 3b). Details of the simulation set up and boundaries conditions are shown in section 3 under “Simulation set up and geometry constraints“ of this paper. The reference material is the structural steel grade S275J wrought.

2.2 Design requirements and Performance indices

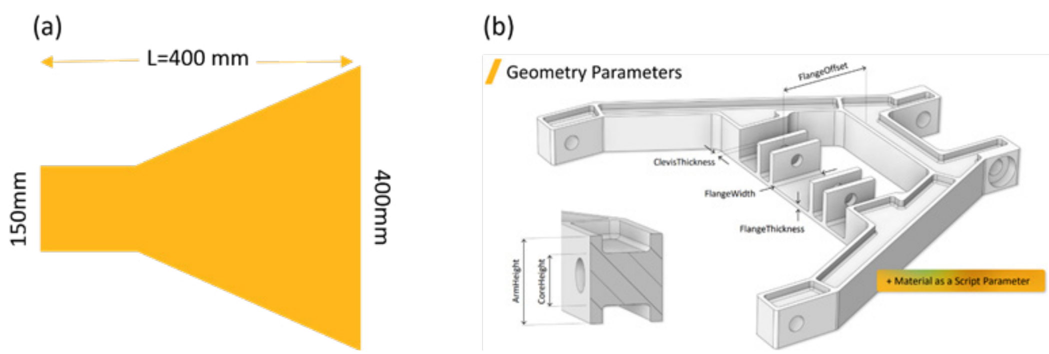

Figure 4. (a) left schematic view of the lower arm as considered for performance index calculation
(b) right CAD view of the lower arm and its geometric parameters used in the optimization stage

Material selection is achieved using the systematic methodology [1]. It consists of identifying the function, objectives, and constraints for the design. The lower arm’s function can be simplified as a beam in bending (cantilever) where we have a fixed length L. As a first approximation we could consider the beam width to be constant over the length and use the performance index finder in Granta EduPack software to find the corresponding performance indices for both strength (cyclic load) and stiffness limited design with mass as an objective. A more realistic approach is to consider that the beam has a width linearly dependent with length position (see Figure 4a). This scenario is not represented in the performance wizard of the Granta EduPack chart stage and needs detailed calculation of the beam moment and of second moment. For simplicity we provide directly the changes on the performance index in the strength limited design. The selection criteria used are summarized here:

Table 2. Summary of the design requirements for the lower arm

Function	Constraints	Objectives
• Beam loaded in bending • Stiffness and strength-limited design • Length and shape specified • Thickness free variable	• Materials subset: metal family • Materials data for simulation available • Compatible with forging/rolling	• Minimize mass • Minimize displacement $M_1 = \frac{\rho}{E}$ $M_2 = \frac{\rho}{\sigma_e^{1/2}}$

2.3 Ranking materials candidates using Granta EduPack

The material selection can be achieved in any of the Level 3 databases. The Granta EduPack Sustainability Level 3 database will be used to benefit from the comparison table capabilities and more detailed environmental and social data availability later.

The search function is used to find our starting material, Structural steel S275J, which is then set as a reference using the right click menu on the record. We then move to chart/select section, and use the subset "all bulk material" for selection project. We first add 2 stages to apply the constraints: one limit stage to consider only metals ferrous + non-ferrous grades which are in the materials data for simulation subset; one Tree stage to include only materials compatible with hot open, hot closed and cold closed die forging processes. We then create a Chart/index stage, plotting on each axis the 2 performance indices calculated earlier.

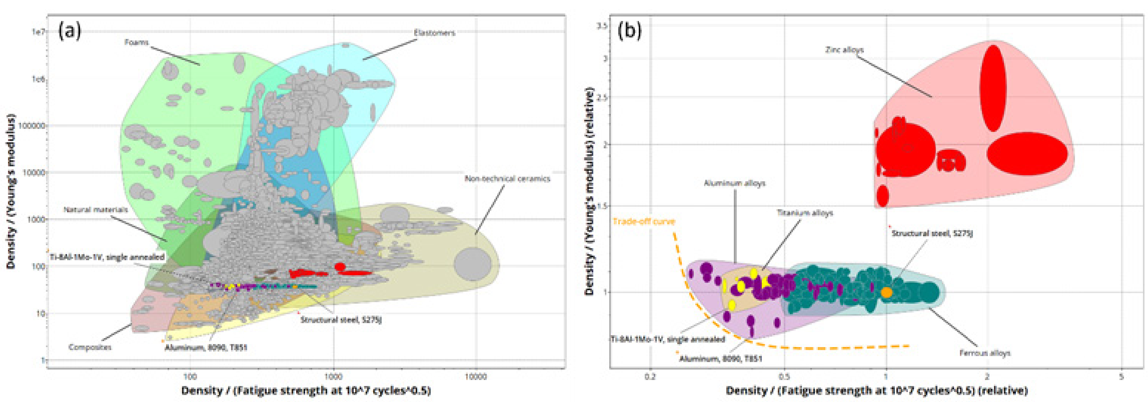

Figure 5. Materials selection charts created with Granta Edupack software (a) with all bulk materials where gray bubbles have been screened by constraints (b) Zoom on remaining candidates

Figure 5a shows the entire materials space for our 2 indices. Figure 5b zooms on the remaining candidates with axis scaled relatively to our reference material, positioned at coordinates [1;1] – this is enabled in the chart parameters. As equations have been derived in such a way that indices are to be minimized to maximize objectives, we seek candidates close to the bottom left corner of the chart. Grades amongst steels, titanium alloys and aluminum alloys that outperform our reference on one or both indices exist. Using a trade-off curve plotted with an orange dotted line, we select one grade of each group which will be used for the rest of the design exploration: Ti-8Al-1Mo-1V, single annealed and Aluminum, 8090, T851.

3. Structural analysis and Geometry optimization

3.1. Simulation set up

The properties of selected materials in Granta EduPack software can easily be used in many Ansys solvers, either by exporting material cards from a selection project and importing the files in the solver, or when using a Granta EduPack software component in a workbench project and connecting it to engineering Materials of the downstream components. For this case study, we have decided to use Ansys Discovery software as it is a good fit for design space exploration: it enables fast live physics simulation and easy parametrization for design of experiment study.

The truck suspension assembly consists of a Chassis, Struts and nuts/bolts component which are not included in the simulation calculations. It also has an upper arm, a lower arm, an upright and a Spindle which is under 7.35kN loading. The lower arm is connected to other components, through two hinged support and one hinged joint. Unless stated otherwise, every simulation is run using the explore mode of Discovery with fidelity configured at 1.42mm. The measured outputs of the simulation are the factor of safety, the maximum displacement, and the maximum Von-Mises Stress. The simulation of our reference design gives a factor of safety of 2.02 with displacement of 0.77 mm, which implies there is space to reduce the volume of material (and hence weight of the part) necessary to fulfill the part's function.

3.2. Design of experiment and geometry constraints

We identified seven parameters that can be changed with the aim of reducing mass and/or improving factor of safety, or stiffness: six geometric (Figure 4b) + the material. Table 3 gives a summary of the parameters, ranges and values we are using as our design space. We also include constraints on geometric dependencies: height difference between Core and Arm has to be larger than 2mm, and Flange thickness has a dependency with Armheight to not interfere with Clevis bolt assembly to the rest of the truck suspension structure.

Table 3. Parameters used and their ranges for the design or experiment and optimization study

Parameter	Reference	Min	Max
FlangeThickness (mm)	12	2	16
FlangeWidth (mm)	55	30	65
FlangeOffset (mm)	90	88	92
ClevisThickness (mm)	5	2	8
CoreHeight (mm)	34	20	40
ArmHeight (mm)	52	34	52
Material	Structural steel S275J	Al 8090 T851	Ti-8Al-1Mo-1V

Ansys Discovery simulation software has embedded parametric study capabilities, which are triggered when adding geometric parameters in the model mode, or when adding any of the simulation set up parameter as a variable (i.e. loading and boundary conditions). Given the quick calculation time of the explore mode, the first approach to explore the design space for our arm is to monitor results directly in the software. The limitations here are that (1) for high order design matrix, the number of simulations to run can quickly escalate when using equally spaced scattering of designs (2) the post-processing capabilities, especially to discuss trade-off and design choice, are minimal.

For these reasons we will make use of Ansys OptiSLang software, which is a process integration and design optimization solution. It uses state-of-the-art machine learning algorithms for design exploration, optimization, robustness and reliability analysis. For simplicity we will not detail the full set-up used in Ansys OptiSLang software and will focus on analysis of the post-processing data.

3.3. Design optimization with Machine learning (ML) and post-processing

Looking at the design space identified earlier, we use the one click optimization wizard in Ansys OptiSLang software and configure it to optimize on mass and max. displacement. At each design calculation, the optimization ML algorithm uses previous system response values to define the next set of parameters to use in the design to get closer to the Pareto front. All designs with safety factors smaller than 1.2 in the simulation results are excluded from the study. This leads to ~700 designs calculated, each simulation run lasting ~2.5min using a Dell Precision 5680, i7-13800H 2500Mhz processor with 14 cores and 32Gb of RAM.

Figure 6 displays the simulated design points against mass of the design, max displacement simulated, and material used for the arm. The reference design is identified in orange on the graph. Given the mechanical and physical properties difference of our three selected material candidates, each design cluster for a given material forms its own Pareto front on the two objectives.

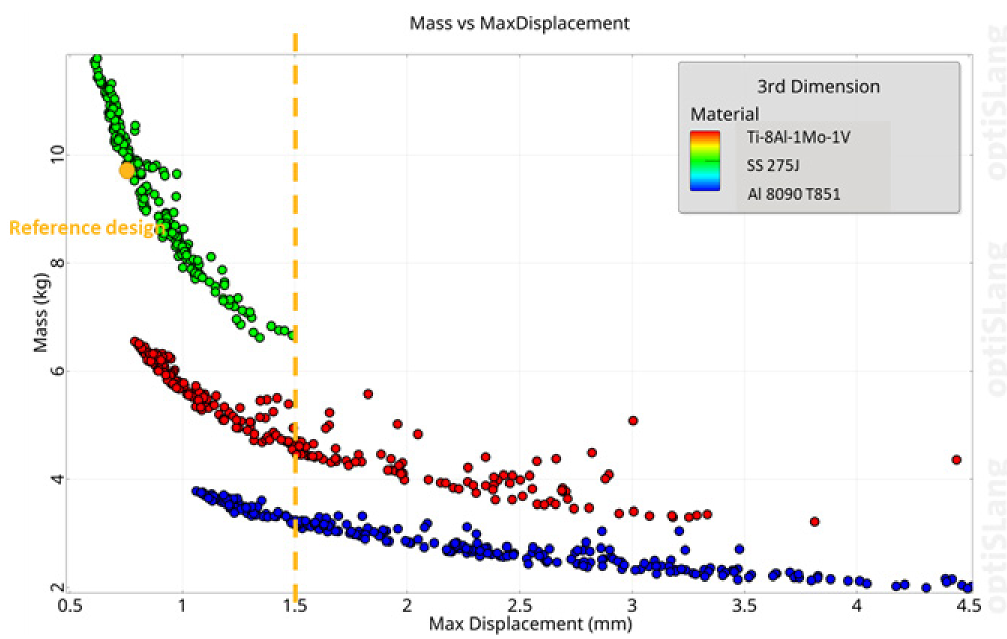

Figure 6. Post processing in Ansys OptiSLang of all design points simulated for each material grade

When addressing trade-off in multi-objective scenarios, one has multiple options at hand to determine a top candidate ranking. The first possibility would be to allocate a weighting factor to each objective and calculate a total optimization coefficient. The second would be to define an exchange function between objectives as explained in the lecture unit “Objectives in conflicts” [2], for example how much more displacement we are ready to allow per kilo saved. This is a common approach in the transport industry where you discuss cost vs. weight (how much are you willing to pay for each kg of lightweighting). The third option is to transform all objectives but one into limits, based on experience, standards, or reference material. We will use the latter. A typical acceptable deflection in mechanical design is in the range of L/200 to L/500. We will opt for L/250, which is in our case a maximum deflection of ~1.5mm. With this new limit, we exclude on our chart designs with max displacement higher than 1.5 and look to optimize mass.

4. Validation and eco-audit assessments of final designs

4.1. Design selection and refine simulation validation

For each material, we select the lightest design with a maximum displacement below 1.5 mm and run an additional simulation using the refine mode of Ansys Discovery simulation software where meshing generation is set to default (279,184 elements for the calculations in our case). Refine mode allows a higher fidelity solution of our problem and is a way to validate results. When doing this step, if the safety factor falls below 1.2, we exclude this design and move to the next best mass design. Table 4 summarizes the selected designs. Compared to the reference, mass is reduced by 16%, 67% and 54% for the SS design, Al design, and Titanium design respectively.

Table 4. Comparison of reference design with selected optimized design on system response

Material	Design ID	Factor of Safety	Mass (kg)	Max displ. (mm)
Structural steel, S275J	reference	2.02	9.98	0.771
Structural steel, S275J	416	1.42	8.23	1.020
Al 8090 T851	86	2.82	3.17	1.497
Ti-8Al-1Mo-1V	689	2.88	4.55	1.490

Figure 7 displays the simulated distribution of von Mises stress of initial design and final designs. The scale has been configured to see at minimum a color gradient in the strongest design. The location of the max stress is circled in yellow: for the reference design and the best aluminum design, it is at the junction of the flange and the clevis. For the improved SS and Titanium designs, it is located at the junction of the flange and the arm at the back of the chosen view. The difference in the results between the explore mode and the refine mode in discovery with higher fidelity remains in most cases below 5%, which is sufficient to be confident in the OptiSLang software optimization approach used.

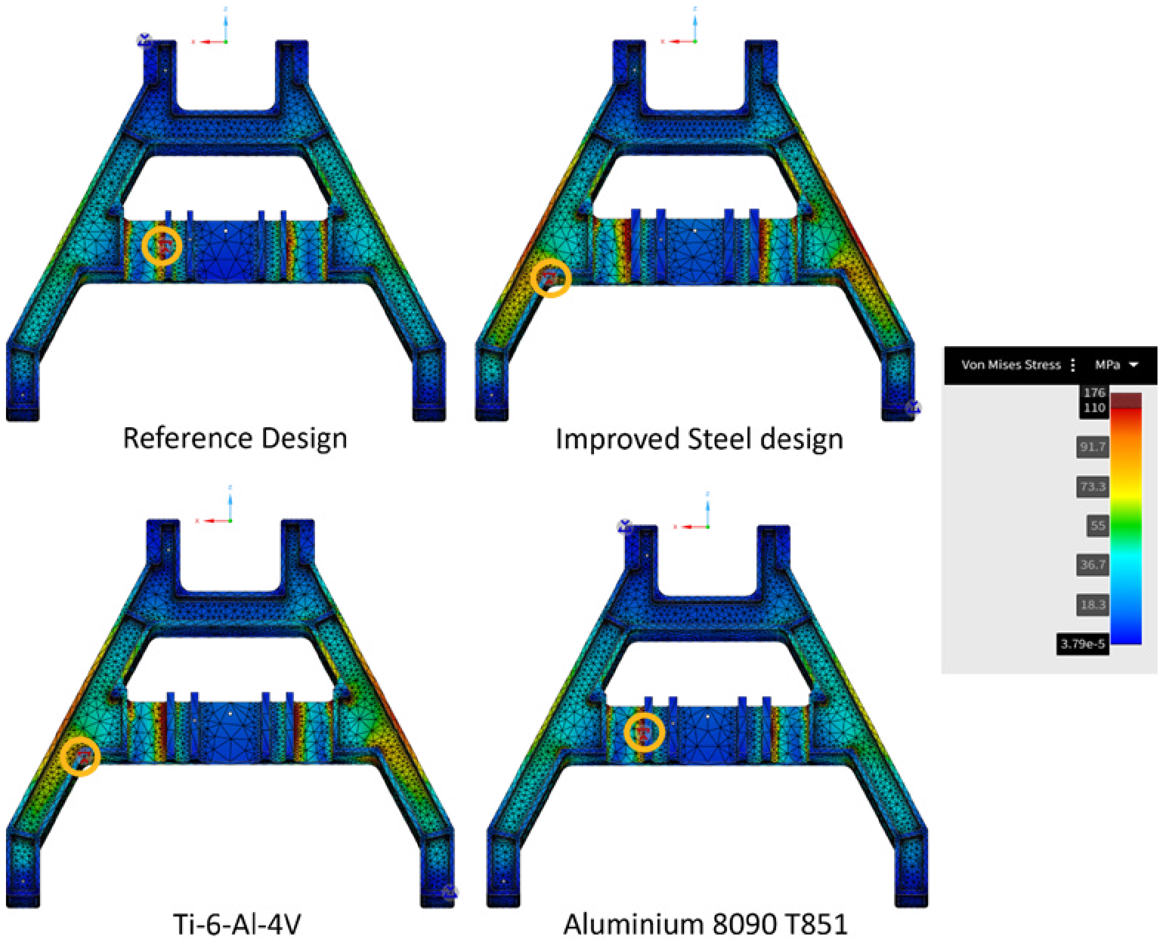

Figure 7. Comparison of Von Mises Stress obtained with Discovery Refine Mode for final designs. Localization of max stress is circled in yellow

4.2. Eco audit assessments of selected design candidates

We use the Granta EduPack Eco Audit Tool to assess the new designs over their life cycle in terms of climate change (CO_2eq) and energy consumption estimations. The reference design is set up with the following scenario:

- Material phase: typical recycled content as it is common supply practice for metal, forging primary process with 0% removed, and Recycled at end of life with 100% recovery as we assume the part to be easily accessible for disassembly
- Transport phase: manufacturing plant to truck assemble, Truck 16-32t EURO3, 500 km
- Use phase: 1 year product life, Mobile mode of a Diesel 14t truck 2 axle, 300 days per year, 270 km. This scenario reflects typical distance before replacement of such part (80 000km)

We then compare different scenarios where only the material and its mass change. Figure 8 shows the comparison of all scenarios in terms of climate change (CO_2eq) impact on which we will focus, but similar analysis using energy consumption could be done. As expected, the improved steel design reduces the overall amount by 16% compared to the reference material in our initial design. For steel designs, the use phase is the most impactful on overall phases.

The comparison between aluminum and titanium designs raises an interesting discussion. While both are significantly lighter compared to steel design, the overall climate change values are quite different: for Aluminum it is 44% less than the reference material, while for Titanium it is 27% higher than the reference material. This is explained by the material phase, which is extremely high for titanium and makes it the largest contributing phase of the life cycle. For the Aluminum, both materials and use phases have comparable impact.

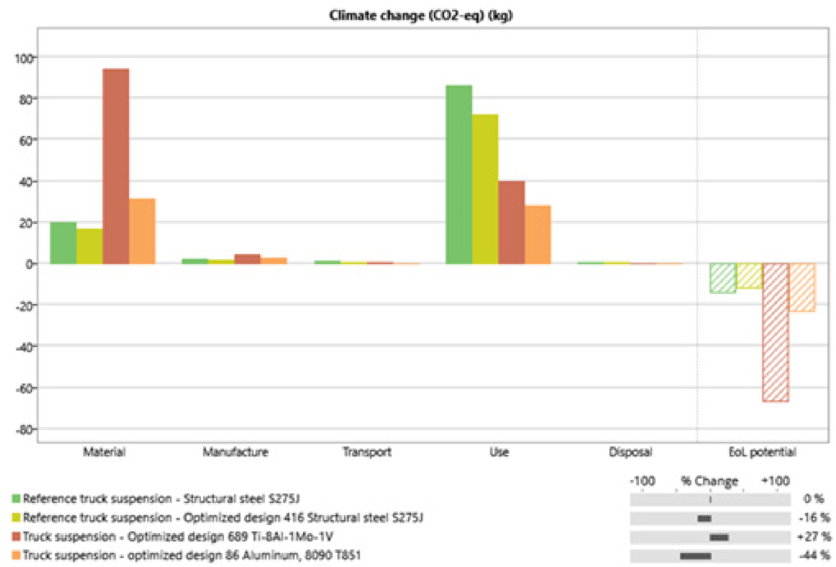

Figure 8. Eco-audit summary chart for climate change metric to compare 4 design options

It is worth noting that for any company reporting on emissions as of 2024, it is mandatory to use scope 2 emissions of the Green House Gases protocol in many parts of the world. This implies assessment of a cradle to gate part of the life cycle (in our case this means only materials, manufacture and transport stages). By being able to look at the full life cycle with Eco Audit tool, including scope 3, one can explore an additional perspective – emissions and energy consumption during the use phase – and promote it as product's value proposition to customers.

A word on the End of Life (EoL) potential visible on the graph: it is not included in typical system boundaries used for standard life cycle assessments and is not taken into account for the Eco-Audit summary calculation, but it enables designers to consider the impact of their design on potential end of life strategies. For example, knowing the benefits that can be achieved by recycling or reusing a material/component at end of life encourages design for disassembly.

The Eco Audit also highlights materials with critical elements of at least 5% in their weight, by triggering an orange icon on the material phase definition. In our case these are Aluminum and Titanium grades. The Critical Materials lists are based on an assessment of the supply risk and economic importance of an element for a given region. These lists are updated on a regular basis. For instance, the European union has its 5th list of 34 CRMs published in 2023. For our selected candidates, these include Titanium, Vanadium, Copper, Lithium, Magnesium. The warning sign in Eco Audit informs users and encourages rethinking their choices to reduce supply chain risk and consider alternatives. You can find more in a lecture unit on topic of Critical Raw Materials [3].

5. Conclusions and perspectives

By applying a combination of tools and methodologies, we have been able to screen an important portion of the design space, with limited time and resources, that could fit our requirements and optimize our objectives. Three alternatives to the initial design have been identified and compared to discuss gains on part weight, its max displacement, climate change and energy consumption impact over product's life cycle. If we were to prioritize environmental impact criteria, this would rank the Aluminum design as our 1st choice.

To push further the analysis, one could extend the scope of the study by considering either

(1) Further explore material space to see if an in between options exists as we have a big gap between the max displacement and factor of safety from improved SS design to Al and Ti designs. This could be if we find the 1.5 mm limit to weak

(2) Working on the whole assembly and re-designing the geometry of other components connected to the lower arm, enabling also more geometry freedom to each part

(3) Explore lightweighting through topology optimization algorithms when generating a new geometry, if additive manufacturing process would be considered, and

(4) Extend to advanced FEA analysis to predict the behavior in fatigue of the redesign component, as it is a function of material and geometry for a part. Fatigue expectancy in normal operating conditions has a direct impact on the use stage of a product, by allowing delayed maintenance. This would modify the Eco-audit assessment.

6. References

1. Ashby, M. F. (2017). Materials selection in Mechanical design, fifth edition . Elsevier.
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