European Economic Letters
ISSN 2323-5233
Vol 15, Issue 2 (2025)
http://eelet.org.uk

Sustainable and Economical Transportation with Optimisation of Cargo Steel Grade and Weight

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Abstract
Weight optimization has increased its importance in recent years concerning global carbon footprints. Lightweight design is one of the current key drivers to reduce the energy consumption of vehicles. Design methodologies for lightweight components, strategies utilizing materials with favorable specific properties and hybrid materials are used to increase the performance of parts for automotive applications. On the other hand, increased safety awareness and global NCAP norms, more focus is on the quality and strength as well. Striking a right balance between these two objectives of opposite ends is a daunting task for automotive designers. But, once done, it will contribute to the circular economy.

There are various approaches to optimize design. This article elaborates on the approach for design optimisation, with real-life case of vehicle cargo design and material selection. Almost 4% weight saving of total closure weight without compromising on quality and durability, can be benchmarked by all OEMs. It can be a guideline for the design engineers to follow in body structure and cargo structure design towards sustainable and economical transportation.

Keywords
Weight Optimisation, Cargo design**,** Automotive Design, Sustainability
JEL Code: Q55, R41, R42

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Introduction

Weight optimization has increased its importance in recent years concerning global carbon footprints. Drivers for weight reduction are common across the automotive industry. On the other hand, increased safety awareness and global NCAP norms (Shaping The Future of Safer Vehicles and Sustainable Mobility, 2024), more focus is on the quality and strength as well. The principles & strategies of implementation for body structures vary between OEM's. The strategies depend upon several important factors such as the ability of the automobile manufacturers to implement changes in manufacturing infrastructures and tooling, the type of product, brand image, etc.

The lightweight design serves as a critical factor in minimizing energy consumption in vehicles. One of the main forces behind the present push to lower vehicle energy usage is lightweight design. To improve the performance of parts for automotive applications, design techniques for lightweight components, strategies employing materials with advantageous particular features, and hybrid materials are employed. Several shaping techniques for creating light pieces are discussed in this work. The manufacturing procedures for creating hybrid components, such as fiber-metal, polymer-metal, and metal-metal composites, which can be utilized in later deep drawing or combination forming processes, are covered in the discussion of material and its lightweight design. (Rosenthal & et.al., 2020)

The actual lightweight degree—a novel concept for assessing the lightweight design of structural components—is created. For stiffness-oriented designs, it is discovered that conventional lightweight characteristics only serve as a lower bound. The minimal underlying design freedom is the cause of this. This is frequently no longer appropriate, though, as modern materials and production techniques usually permit more design flexibility. It is demonstrated using a simplified mathematical model that an upper bound can be obtained by combining the yield strength, the specific Young's modulus, and a requirement-based equivalent strain. This theoretical upper constraint can be used as a good qualitative criterion for the selection of materials that minimize mass, as demonstrated by numerical topology optimizations. The findings show that the degree of design freedom can have a significant impact on the selection of the appropriate material. For instance, an aluminum alloy with a yield strength of 280 MPa allows for a somewhat lighter component mass than a steel alloy with a yield strength of 800 MPa under lower-bound design limitations. On the other hand, assuming full geometric design flexibility results in a significantly lower mass for the steel alloy. However, the idea developed in this work is only applicable to stiffness-oriented, elastically loaded isotropic material components. (Marlon & et.al., 2019)

The entropy-weight technique for order preference by similarity to an ideal solution (EW-TOPSIS) method is suggested to mine the optimal solution in the non-dominated Pareto solution sets in order to enhance the energy-saving and emission-reduction effect of the vehicle front-end structure. Using vacuum investment casting and the integrated optimization design approach, the ZL205A aluminum alloy is used to create the front-end structure of the car. A radial basis function (RBF) - response surface methodology (RSM) hybrid surrogate model is constructed using a finite element model. The optimization objectives are mass and specific energy absorption. A multi-objective optimization is performed in conjunction with a multi-island genetic algorithm (MIGA). The EW-TOPSIS approach is used to score and rank the Pareto solution sets, and the life cycle of the best solutions is evaluated. According to the findings, during a 300,000 km driving range, the optimized cast aluminum structure lowers mass by 49.82%, enhances energy absorption by 37.70%, and lowers energy consumption by 4776.674 MJ and greenhouse gas emissions (GHG) by 176.207 kg. (Li & el.al., 2024)

A new method for choosing materials has been created and incorporated into software. The process uses performance indices, which are combinations of material qualities that control performance, and materials selection charts, which are a new method of displaying material property data. Optimization techniques are used to choose the material and shape at the same time. (Ashby & Cebon, 1993)

Through goods and services, modern production makes it possible for people all over the world to live comfortably. A thorough integration of sustainable development promoted by novel paradigms, cutting-edge technologies, techniques, and tools, as well as business models, is necessary for global responsibility. Important facets of future production include reducing material and energy use, modifying material and energy flows to better suit natural process capacity, and altering consumption patterns. In management and engineering, a life cycle perspective and an integrated economic, ecological, and social evaluation are crucial prerequisites. Based on life cycle thinking, this series will concentrate on the problems and most recent advancements in manufacturing sustainability. (Egede, 2017)

Morphing structures are those that change size and shape when a stimulus is applied. Because of its advantages over traditionally utilized materials, this topic has attracted the attention of many researchers worldwide. Few research have been done especially for automotive applications, and the majority of documented morphing investigations are restricted to aerospace applications. The applications of morphing technology in automobiles are covered in this study, with a focus on widely used smart materials such as elastomers, shape memory polymers, and shape memory alloys. It also covers systems like sensors and actuators that are necessary for the operation of morphing structures. We've discussed a few morphing applications in cars. An effort is made to relate the results of aerospace research to possible automotive applications since some studies on the evolution of aerostructures can be applied to the automotive sector. (Anumodh & et.al., 2021)

High-strength aluminum alloys have garnered significant scientific and technological interest in the domains of vehicles, high-speed railroads, aerospace, and navigation because of their exceptional strength, toughness, and resistance to corrosion. However, when the strength of high-strength aluminum alloys increases, their impact and fracture toughness drop. There are now three primary control tactics to address the aforementioned contradiction: modifying the alloying materials, creating novel heat treatment procedures, and employing various deformation techniques. In order to determine if it is feasible to match high-strength aluminum alloys in terms of strength and toughness, this study first examines the current issues with the production of high-strength aluminum alloys. It next reviews the mechanisms of strengthening and toughening in high-strength aluminum alloys. The research progress towards modifying the technology of high-strength aluminum alloys based on theoretical analysis and experimental verification is then summarized in this paper. This includes new ideas for high-strength aluminum alloy research as well as the modification of process parameters and the resulting mechanical properties. Lastly, a methodical emphasis is placed on the primary issues, difficulties, and future research directions related to the toughening and strengthening of high-strength aluminum alloys. It is anticipated that this work may offer workable new concepts for the creation of aluminum alloys with high strength and hardness, high dependability, and extended service life. (Zheng & et.al., 2022)

For sheet metal components, the paper focuses on material optimization through raw material size reduction. An car part, the panel roof, is selected for examination. A commercial explicit solver is used to analyze the sheet metal-forming process. A computer-aided design (CAD) model of the tool geometry is created by scanning the die in a coordinate measuring machine (CMM) in order to depict the actual tool profile in the analysis. The finite element analysis (FEA) verifies the forming limit diagram (FLD) and the thickness reduction %. The circular grid analysis technique is used to experimentally verify the optimized blank. Major strain differences range from 2 to 10%, while small strain differences range from 0% to 6%. In the current work, weight savings of around 1.57% are obtained. (Hariharan & Balaji, 2009)

The primary limitations caused by the requirement to join thin-walled tubes of low to medium diameter size made from materials that are not suitable for welding and/or have reduced contact interfaces can be resolved by joining tubes to tubes using plastic deformation at room temperature. By using an accessory lightweight sheet metal flange that is subjected to annular indentation and then injection of its material towards the tube walls to create a mechanical interlock between the various elements, the new joining solution enables one to obtain permanent mechanical joints of tubes or pipes. With the help of fasteners or other joining accessories fastened to the sheet flange, the connected tube assembly can then be used to attach to walls or other various buildings and equipment. It is simple and safe to generate identical or dissimilar material combinations while ensuring degrees of leak-tightness within the individual tubes' maximum internal operating pressure. Depending on the application, pull-out loads and internal fluid pressure are applied to the produced joint to assess how it will behave under normal operating conditions that it may encounter over the course of its service life. (Afonso & Alves, 2023)

A framework for material-structure optimization of a multi-material frame body is suggested in order to simultaneously increase lightweight and collision safety. First, the load path of the frame body is analyzed using the equivalent static load method to determine the best structure for increasing the crashworthiness of the frame. Second, each frame body member is assessed using the crashworthiness evaluation method based on evolutionary structural optimization (ESO) method, which serves as the foundation for material selection. Ultimately, the multi-material frame with the objective selection scheme is produced by using the bubbling technique-based material selection method to choose materials in an orderly manner that corresponds to the members' functions. The lightweight racing vehicle body used in this study serves as an example of the suggested approach. According to the data, the lightweight design improves crash safety while reducing body mass by 25.60 kg. (Wang & el.al, 2024)

This paper discusses several approaches and tactics for achieving the best lightweight body forms. This is accomplished by analyzing individual panels for mass optimization of important factors such as stiffness, formability, reinforcing requirements, form changes, etc. Every strategy is created with the fewest tooling modifications possible. The ultimate goal is to increase the stiffness to mass ratio without sacrificing durability or quality. Each component is examined separately, and some alterations are included along with thorough case studies of certain components.

The body structure for pick up consists of two subsystems namely Cabin system and Cargo system. The cargo subsystem engineering performance is typically measured with Bending stiffness and torsional stiffness. The overall bending and torsional stiffness is dependent on the subsystem i.e. sidewalls, front walls, underbody and tail gate. The approach followed is to set the target, as benchmarked, for these parameters and optimize on sections and materials so that there is no compromise on any engineering parameters.

Anything to be improved should be measured. Most of the tools are subjective and difficult to measure and improve. FMEA provides an opportunity to do objective evaluation by quantifying the risk. But it is not limited to risk and provide an opportunity for holistic product development process and optimize all the aspect of world class product development including cost, time, and efforts. (Dhande, 2016)

Weight optimization of Cargo box:

With an overall weight of 218 kg, the current pick-up vehicle's cargo box is made to have a tensional stiffness of roughly 460 N-M/deg and a bending stiffness of 2000 N/mm. The difficulty lies in maintaining rigidity and other engineering factors while lowering the total weight.

The side wall is taken into consideration, for instance. Determining the side wall's base line stresses and deflection is the process used. Plots of deflection and Max Von Mises stress are produced. In order to determine its impact on stiffness values, the initial optimization was done with decreasing thickness. The side panel thickness was lowered to 1.00 mm and the sill floor thickness was 1.6 mm from the base line of 1.2 & 2 mm thickness in the base line model with two loads.

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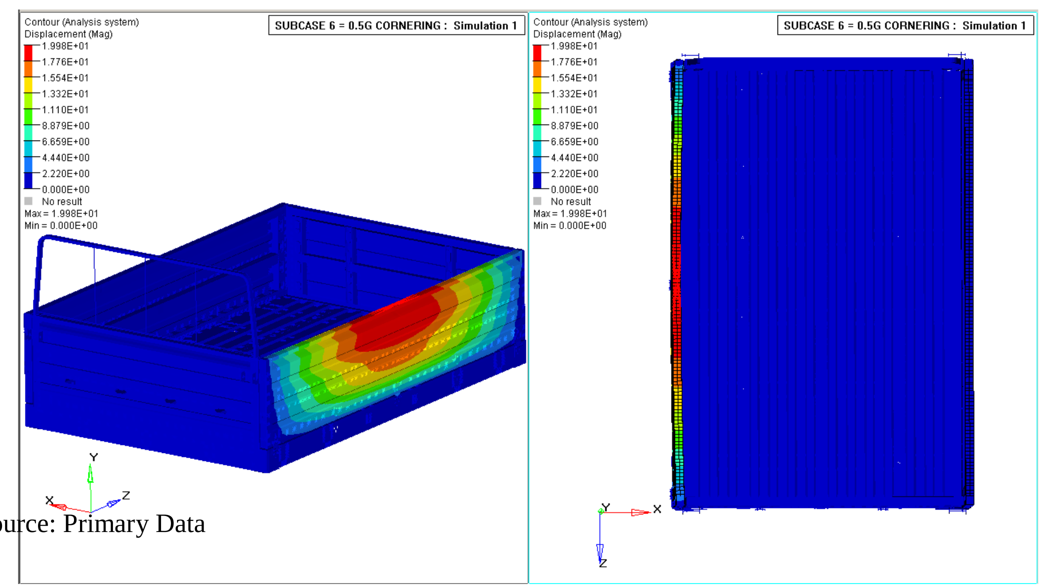
Table 1: Summary of Base Line and Iteration 1

S.No	Components	Thickness (mm)	Load (tones)	Deflection (mm)	Stress Mpa Side top	Bending Stiffness	Torsional stiffness
Base line	Side Panel	1.2	2.5	Base	Base	@ 2000 KN/mm	@460 N-M/deg
	Sill floor	2					
Iter 1	Side Panel	1	2.5	12% high	17% high	@1800 N/mm	@ 450 KN-M/deg
	Sill floor	1.6					

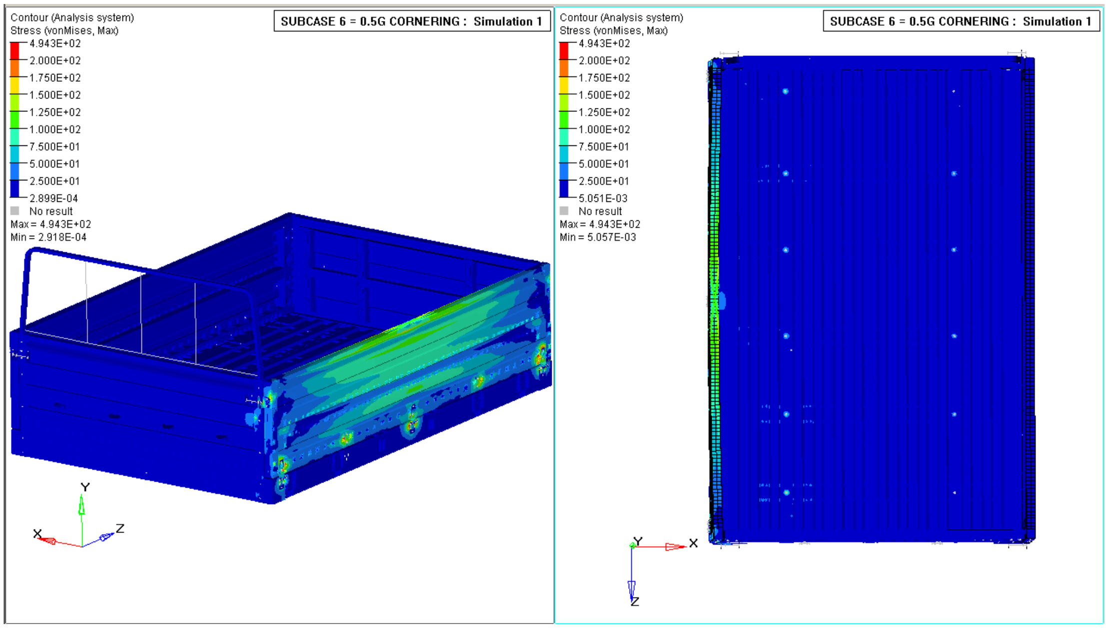
Only the thickness reduction significantly degrades the product's performance, according to the baseline and iteration 1. In order to improve product performance and reduce weight, it was necessary to increase the section modulus. The stiffness to mass ratio may increase as a result. Another forming problem is the reduction in thickness. By altering the beading pattern and constructing a box section at the appropriate spot, the enhanced section modulus is accomplished. The max Deflection and stresses with improved section modulus is shown in below figures 1& 2.

Fig. 1: Deflection plot for Final Iteration



Source: Primary Data

Fig. 2: Max, Vonmises Stress Contour plot



Source: Primary Data

The stiffness requirements in reduced thickness were satisfied by adding a hat portion and altering the beading pattern. As a result, this optimization method reduced the weight by roughly 18–20 kg, and the side and sill panels were shaped with altered geometry. This was additionally put through a 50,000-kilometer general highway durability test, a four-poster abuse test, an accelerated durability test, and a high speed durability test. It passed each of these dependability tests without experiencing any structural issues.

Weight & steel grade optimization of body closure

A vehicle's body closure components make up over 30% of its entire weight, therefore weight optimization is a top priority. The closure panels' material, forming severity, and general form were examined throughout many brainstorming sessions for weight optimization. The study provided guidance on how to use materials with a higher yield strength to optimize weight. Compared to candidate steels with higher strength, the current material has a superior formability. Therefore, using high strength steel to optimize weight in order to fulfil current technical criteria presents forming issues. Utilizing the die and press facilities that were already in place was another restriction.

Bead clearances, cushion pressure, and other forming parameters were adjusted on a case-by-case basis to achieve the necessary closure panel form and geometry. In several instances, the numbers and bead placements were changed. As a result, a total of 4% weight reduction was accomplished with minimal tool investment and without sacrificing quality or durability. From ideation to the actual installation of enhanced closing panels, this was accomplished in ten months.

Conclusions:

1. 18-20 kg weight which is about 10% of total weight of Cargo box was saved in one of the optimization projects for Pick up vehicles.
2. In the case of body panel weight optimization process the forming challenges were overcome by using of higher yield strength material leading to weight saving of about 4% of total closure weight.
3. We can achieve the weight optimization of vehicle formed parts without compromise on part quality & durability.
4. The approach can be useful towards sustainable and economical transportation.

5. Summary:

1. Vehicle weight optimisation is becoming more or more essential and critical towards achieving the aim of lower carbon footprint. At the same time, adherence to the quality norms and strength is also becoming critical on the backdrop of increased safety awareness and global NCAP norms. Striking a right balance between these two objectives of opposite ends is a daunting task for automotive designers.

2. There are various approaches to optimize design. This article elaborates on the approach for design optimisation, with real-life case of vehicle cargo design and material selection. Almost 4% weight saving of total closure weight without compromising on quality and durability, can be benchmarked by all OEMs. It can be a guideline for the design engineers to follow in body structure and cargo structure design. Also it will be contribution to the environmental sustainability in transportation and overall circular economy.

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