



## Generative Design Case Study for Eco-Efficient Vehicles Lower Emissions and Greater Range

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# Generative Design case study for Eco-Efficient Vehicles: Lower Emissions and Greater Range

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**Abstract**— The application of AI, or artificial intelligence, offers a novel opportunity to advance generative design in a number of mobility-related fields. The method allows for the creation of parts to be completed in a shorter time frame and has the objective of achieving multiple sustainability goals with minimal information provided at the outset. This article will present a practical case study of this method on an automotive Engine mounting bracket, a complex part that must meet a range of requirements, including those related to rigidity, strength; and sustainability. The initial 3D model will define the space constraints (design space), operating conditions, and objectives to be achieved. These may include, for example, improvements in rigidity, lightweighting and fatigue, reductions in CO2 impact, and improvements in autonomy. The result is a set of designs that respect the constraints and maximize the objectives. Subsequently, the designer may select the design that is most aligned with their preferences, taking into account additional considerations such as manufacturing simplicity, or cost. A comparative analysis was conducted between generative design and traditional design, which relies on human expertise, CAD (computer-aided design) tools, and algorithms. The weight, deformation, stress, fatigue, CO2 emissions and self-sufficiency performance of the two methods were evaluated. It was found that generative design allows for a 30% reduction in the weight of the part compared to traditional design, while simultaneously improving its rigidity and strength. The total weight reduction of many brackets for the same vehicle also results in a decrease in CO2 by 3.5 g/km and an increase in autonomy by 2.8 km.

**Keywords:** Topology optimization; Engine mounting bracket; computer-aided design; lightweighting; sustainability; retro engineering; FEA; fuel consumption;

## I. INTRODUCTION

Optimizing vehicle components is a key challenge in a world where energy efficiency and carbon footprint reduction have become key priorities for the automotive industry. Engine mounts bracket[1], as key elements of a vehicle's structure, play an essential role in safety, comfort and overall performance. This article presents an advanced study on the use of generative design to optimize a left engine mount bracket, building on the methodology and approaches previously applied to the optimization of an engine mount bracket. The aim was to create an engine mount bracket that is not only lighter, but also more

efficient in terms of stiffness and environmental performance, using the advanced capabilities of artificial intelligence and computer-aided design (CAD).

The approach taken in this research is based on the use of cutting-edge generative design software, which enables the generation of optimized shapes according to mechanical constraints and performance objectives. This method, which has already been proven effective in the optimization of components such as pistons[2], is applied here to the design of engine mounting bracket with the aim of reducing mass, increasing range and achieving significant reductions in CO2 emissions.

The results show promising progress, paving the way for lighter, more economical and environmentally friendly vehicles. This study thus contributes to the evolution of the automotive industry towards an era of more sustainable and intelligent design, where every gram saved counts for the future of our planet.

## II. METHODOLOGY

### A. Engine mounting Bracket selection

The engine mount is a component that attaches and supports the engine to the vehicle chassis. It plays a key role in reducing vibrations, noise, and mechanical stresses. Therefore, it must be designed carefully to ensure the safety, comfort, and performance of the vehicle.

To select the engine mount to study, we followed these steps:

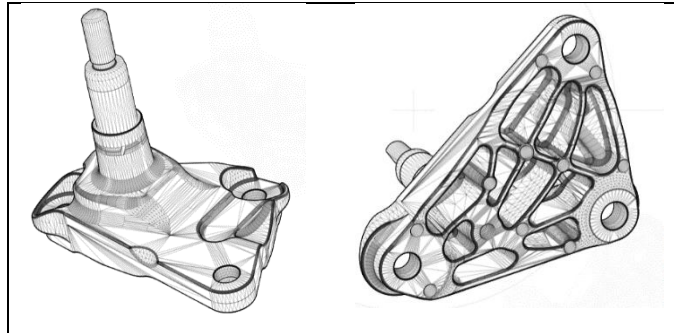
a. Reverse-engineering of the existing mount: we analyzed the engine mount of an existing vehicle model. We measured its dimensions, weight, material, manufacturing method, etc. We also identified the loads and stresses it is subjected to, as well as the performance criteria it must meet.

b. Evaluation of the existing mount: we evaluated the existing mount according to feasibility, profitability, impact, and priority criteria. We considered the technical, economic, environmental, and strategic aspects of the mount. We found that the existing mount presented opportunities for improvement by generative design, especially in terms of weight reduction, strength increase, shape simplification, and cost reduction.

c. Selection of the mount to study: we selected the engine mount as the part to study, respecting the budget, schedule, and objectives of the project. We chose this mount because it offered the most potential for added value, differentiation, and competitiveness for the vehicle.

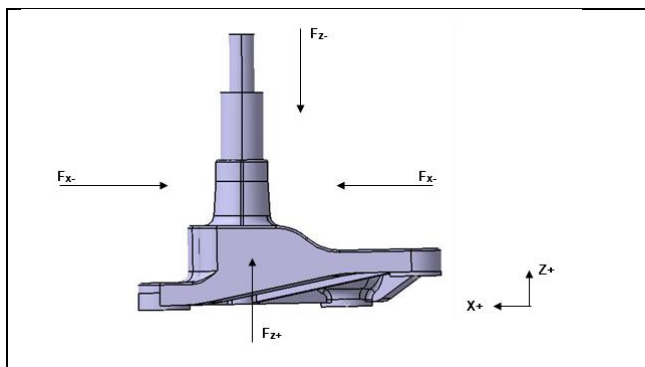
**B. Technical specifications of part to study**

Engine mount bracket is aluminum (AS9U3 Y40) part that connects the engine to the vehicle chassis. It must support the weight of the engine, absorb vibrations and shocks, and resist high temperatures. Its technical specifications are as follows:



**Figure 1.** Basic design of engine mount bracket.

- Weight: 500g
- Forces (see table 1)



**Figure 2.** Application of forces

**Table 1.** forces applied to the engine mount bracket

Vehicle direction	Nominal forces (N)	Maximum forces (N)	Exceptional forces (N)	Fatigue equivalent 10 <sup>6</sup> cycles (N)
X+	2000	3020	4000	2500
X-	1500	2500	4000	2500
Y		1300	2000	+/- 1300
Z+		2500	4200	1010
Z-	850	4250	5900	4390

This mount was chosen for optimization by generative design because it has the following characteristics:

- It is subject to well-defined forces and stresses, which can be modeled and simulated.
- It has a complex geometry, which can be simplified and rationalized.
- It has a considerable impact on the weight, performance, driving experience and the vehicle's safety.
- It can be manufactured by advanced processes, such as 3D printing, which allow for innovative and optimized shapes [3]

**III. SIMULATIONS AND RESULTS**

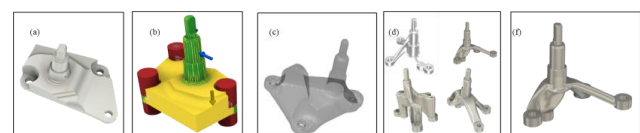
**A. Analysis**

Generative design represents an innovative method that integrates topology optimization with deep learning models, allowing for the exploration of a wide range of designs. This approach aims to align the engineering performance and the visual appearance. The process leverages algorithms to generate new forms by iteratively refining designs based on pre-defined objectives. In particular, the integration of Generative Adversarial Networks (GANs) allows a more extensive design space to be considered, often resulting in unexpected, original and efficient forms that challenge traditional design boundaries [4].

Generative design using Fusion 360 [5], as shown in Figure 2 (b), begins with the definition of the design space. The green bodies indicate the regions where material must be kept, while the algorithm efficiently connects these regions with material flow based on linear FEA calculations and the level set method. The red bodies serve as obstacles, ensuring that material flow avoids these regions, thus maintaining the required clearances and specific mounting regions for different components.

Various load scenarios are then defined, with the parts aligned parallel to the machining directions. The forces, derived from body of vehicle and engine, are then expressed in the coordinate system. The material used is AS9U3 Y40, with a yield strength, and the objective function is set to minimize mass.

Finally, utilizing casting- CNC 3-axis machining [6] and additive manufacturing, the generative design results for the engine mount, shown in Figure 2 (d), show that the algorithm has connected the save regions in a pattern that distributes the material as far away from the longitudinal plane as possible.



**Figure 3.** Generative design process: (a) initial part, (b) Prepared part, (c) Density profile, (d) some generated parts, (e) selected part

To prevent any failure in the system under real conditions, it was necessary to determine the critical constraints to validate the

generated design and compare them with the initial design. The distribution of constraints in the engine must ensure sufficient rigidity as specified by the following technical specifications in the Table 2

**Table 2.** Technical specifications AS9U3 Y40

force scenarios	Validation Criterion in Stress
Exceptional force	$\sigma_{max} < 2 * \sigma_e = 280 \text{ MPa}$
Maximum force	$\sigma_{max} < \sigma_e = 140 \text{ MPa}$
Fatigue force	$\sigma_{max} < \sigma_e/2 = 70 \text{ MPa}$
Modal Criterion	The first eigenfrequency of the part must be greater than <b>650 Hz</b>

where  $\sigma_e$  is the Yield strength.

**B. Static Stress Analysis: Legacy Design**

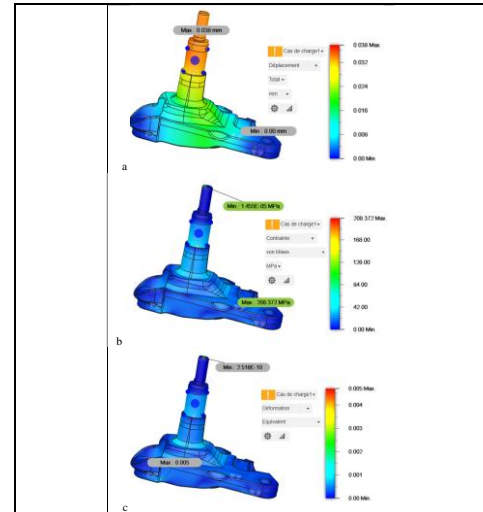
The results of the static simulation for the initial design and generative design shown in displacement, stress, and strains maps[2] (see figure 3 and 4) and the maximum and minimum values for each measure (see tables 3 and 4).

**Table 3.** Stress analysis for the legacy design of engine mount bracket

Name	Maximum	Minimum
<b>Weight</b>	0.415 kg	
<b>Volume</b>	1.538E+05 mm <sup>3</sup>	
<b>Safety Factor (Normal force)</b>	2.638	
<b>Stress</b>		
Max Von mises	208.4 MPa	0 MPa
Max 1 <sup>st</sup> Principal	53.1 MPa	-95.43MPa
Max 3 <sup>rd</sup> Principal	7.35 MPa	-247.67 MPa
<b>Displacement</b>		
Total	0.038 mm	0 mm
X	0.004 mm	-0.01 mm
Y	0.006 mm	-0.005 mm
Z	0.001 mm	-0.037 mm
<b>Reaction Force</b>		
Total	203.41 N	0 N
X	73.75 N	-71.22 N
Y	30.79 N	-48.88 N
Z	188.12 N	-68 N
<b>Strain</b>		
Equivalent	0.005	0
1 <sup>st</sup> Principal	0.002	0
3 <sup>rd</sup> Principal	0.00	-0.005
<b>First eigenfrequency</b>	2137.57 Hz	

As shown in Figure 4(a), the maximum displacement of the component is 0.038 mm, while the minimum displacement is zero (0 mm), indicating good structural rigidity under the applied load conditions. However, the absence of displacement in certain areas may suggest uneven load distribution or overengineering in some parts of the component. Figure 4(b) presents the applied case loadings, specified as 0 MPa, and a maximum design stress of 208.4 MPa, as indicated in Table 3. Although this stress level complies with design specifications,

further evaluation is necessary to ensure it remains below the material's yield strength, avoiding any risk of plastic deformation or premature failure. Figure 4(c) illustrates the original design strain, with values ranging from 0 to 0.005. While this strain range is typical for a ductile material, a more detailed analysis is required to verify that the overall behavior of the component under applied loads stays within acceptable limits. Lastly, Table 3 summarizes the results of the analysis performed on the legacy design, outlining the component's performance under these specific conditions.



**Figure 4.** Stress analysis for the legacy design: (a) Displacement (b) Stress (c) Strain

**C. Static Stress Analysis: Generative Design**

**Table 4.** Stress analysis of the generative design of engine mount bracket

Name	Maximum	Minimum
<b>Weight</b>	0.319 kg	
<b>Volume</b>	1.180E+05 mm <sup>3</sup>	
<b>Safety Factor (Normal force)</b>	2.61	
<b>Stress</b>		
Max Von mises	279.64 MPa	0 MPa
Max 1 <sup>st</sup> Principal	345.34 MPa	-27.97 MPa
Max 3 <sup>rd</sup> Principal	71.43 MPa	-122.73 MPa
<b>Displacement</b>		
Total	0.552 mm	0 mm
X	0.003 mm	-0.55 mm
Y	0.04 mm	-0.003 mm
Z	0.07 mm	-0.082 mm
<b>Reaction Force</b>		
Total	910.45 N	0 N
X	742.78 N	-231.267 N
Y	555.72 N	-783.98 N
Z	558.17 N	-489.29 N
<b>Strain</b>		
Equivalent	0.007	0
1 <sup>st</sup> Principal	0.007	0
3 <sup>rd</sup> Principal	0.00	-0.004

A similar stress analysis was performed for the generative design of the engine mount bracket. The maximum displacement of the component was recorded at 0.552 mm, decreasing to 0 mm, as illustrated in Figure 5(a). This significant displacement, compared to the legacy design, suggests that the component may experience greater flexibility or deformation under the specified load conditions. However, the absence of displacement in certain regions may indicate areas of increased rigidity or an uneven distribution of mechanical loads. As shown in Figure 5(b), the maximum design stress reached 297.64 MPa. Although this stress level exceeds that of the legacy design, it remains subject to evaluation against the material's yield strength to ensure structural integrity and prevent plastic deformation. Figure 5(c) presents the strain, which varies between 0 and 0.007. This increased strain range suggests a higher degree of material deformation in the generative design, which should be carefully analyzed to ensure it does not exceed acceptable thresholds for long-term performance and durability

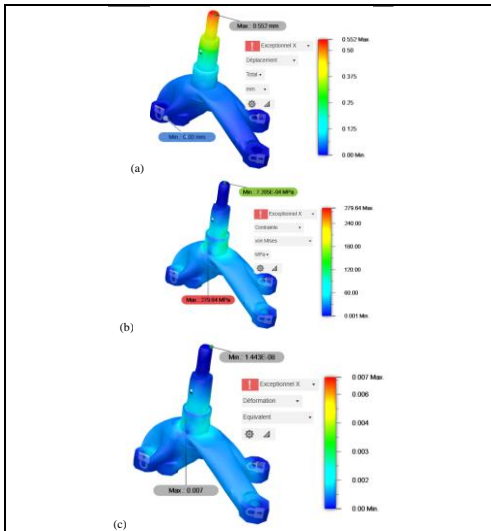


Figure 5. Stress analysis for the generative design: (a) Displacement (b) Stress (c) Strain

According to the analysis for each force scenarios, all the criteria of the specifications are validated (see table 5)

Table 5. Synthesis of calculation for AS9U3 Y40

Force scenarios by Direction	Exceptional Force	Maximum Force	Fatigue Force
X+	187 MPa	131 MPa	58 MPa
X-	187 MPa	117 MPa	58 MPa
Z+	85 MPa	51 MPa	10 MPa
Z-	164 MPa	118 MPa	61 MPa

#### D. Analysis of engine mount bracket optimization results and discussions

The analysis of the provided results highlights the benefits of optimizing the engine mount in terms of weight reduction, fuel consumption, and CO2 emissions

Table 6. Performances comparison

	Initial Engine Mount	Optimized Engine Mount
Weight (kg)	0.500	0.350
Weight reduction (kg)	0	0.15
Fuel consumption (l/100km)	7.5	7.498875
Consumption reduction (l/100km)	0	0.001125
CO2 Reduction (g/km)	0	2.61
New CO2 Emission (g/km)	175	172.39
Range (Km)	1066	1066.12

- Weight Reduction

The initial engine mount weighs 0.500 kg, while the optimized version weighs 0.350 kg, resulting in a reduction of 0.15 kg. This represents a 30% decrease in weight, demonstrating the direct impact of weight reduction on the overall vehicle performance, as shown by the work of James COULTHARDA and Chang Jiang WANG[7], who achieved mass optimizations of up to 88.13% using generative design coupled with additive manufacturing.

- Fuel Consumption

Regarding fuel consumption, the initial engine mount leads to a consumption of 7.5 l/100 km, while the optimized mount reduces this to 7.498875 l/100 km, a modest reduction of 0.001125 l/100 km. Although small in absolute terms, this reduction shows the potential for cumulative savings over longer distances. According to a study by the School for Environment and Sustainability University of Michigan in 2018, a 10% reduction in mass leads to a decrease in fuel consumption of 6% to 23%[8]. In addition, Current technological cost estimates indicate that the best main mass reduction, which minimizes total costs, is comparable for both conventional and electric vehicles, ranging from 22% to 39%[9].

- CO2 Emissions Reduction

One of the most notable results is the decrease in CO2 emissions. The optimized engine mount enables a reduction of 2.61 g/km, lowering emissions from 175 g/km to 172.39 g/km. While moderate, this improvement is significant in the context of increasingly stringent environmental regulations. It can be noted that the average reduction in vehicle mass without powertrain resizing can lead to a fuel consumption reduction of between 1.9% and 3.2% in ICE vehicles [10].

- Vehicle Range

The engine mount optimization also slightly affects the vehicle's range. The initial range is **1066 km**, compared to

**1066.12 km** after optimization. Though minimal, this difference indicates a slight increase in overall efficiency. These results are consistent with those obtained by Jost Williame, who showed that lightening the weight of electric vehicles can improve their range by 6% to 8% [11]

#### E. Comparison with other studies

Our study is not the first to optimize engine mounts. Several research projects have been carried out in this area, sometimes with similar objectives others with different methods and approaches. Here we present some examples of these studies and compare them with our work.

Kumar achieved a 9.97% mass reduction on an engine mounting bracket using topology optimization, resulting in structural improvements but with a significantly lower reduction than our 30% [12]. Similarly, Sowmya focused on optimizing an after-treatment mounting bracket for emission compliance, reducing the number of parts and mass but did not specify achieving such a high reduction [13]. Cyril and Manikandan explored engine and transmission mounting optimization with a focus on noise, vibration, and harshness (NVH) performance improvement, without the same emphasis on mass reduction as a primary goal [14]. Finally, Lee and Singh provided a critical analysis of hydraulic engine mounts but did not focus on mass reduction as a key outcome [15]

In contrast, our results demonstrate a more substantial mass reduction, leading to direct fuel savings, an increase in vehicle range, and a significant reduction in CO2 emissions. This comprehensive impact on vehicle performance, sustainability, and operational costs clearly surpasses the focus and outcomes of the previous studies.

#### IV. CONCLUSION

This paper outlines the importance of generative design as a revolutionary optimization tool. It not only reduces mass and enhances stiffness, but also significantly decreases fuel consumption, extends vehicle range, and cuts CO2 emissions. When applied to vehicle supports—which constitute approximately 10-15% of the vehicle's total mass—this method can achieve up to a 4.5% reduction in total vehicle weight. Remarkably, these benefits are realized without compromising any of the vehicle's various systems.

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