



School of Engineering

MSc Mechanical Engineering

M7X01380 – Simulation and Modelling

Assignment 2 – Optimisation in the Design Process

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Abstract

The report considers the application of topology optimization to an engine mount bracket used in an automotive application, where weight reduction is the optimization objective. The manufacturing optimization constraints imposed by a traditional high pressure die casting process, and an additive manufacturing process, selective laser melting, is considered.

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1.0 Introduction

With an ever-increasing focus on the environmental impact of internal combustion engine motor vehicles an important design consideration in reducing fuel consumption and in turn emissions is in reducing the weight of the vehicle. Cheah (2010), suggests that fuel consumption is reduced by 7% for a 10% reduction in vehicle weight, where redesign and the application of lightweight materials is applied. The report considers the optimization of an automotive mounting bracket used for the support of an internal combustion engine, where weight reduction is considered as an objective, and stress and displacement are considered as constraints. The mounting bracket is manufactured as a high pressure die cast aluminium component; typical examples being detailed in figure 1.



Figure 1. Typical aluminium mounting brackets (Ozay Dokum, 2019)

Computer aided engineering and optimization techniques are well established in the automotive industry (Jones, 2003). The application of optimization led design in manufacturing results in significant savings both in time taken from concept to production, and also in the materials required in the manufacturing process while meeting or often exceeding the design specification requirements. A traditional computer aided design approach typically involves repeated cycles of design, manufacture, and testing. Where the product evolves over several cycles before arriving in the final production design. Introducing computer aided engineering into the design process allows component optimization in terms of variables, objectives and constraints during the conceptual and computer aided design phases by integrating computer analysis. The analysis utilises finite element algorithms, where the structure design is optimized through an iterative process. The resultant computer analysis provides an indication of the most efficient shapes and dimensions for the component based on the specified design parameters, which in turn is incorporated into the developing computer aided design model. Figure 2 describes the simplification of the design, manufacturing and testing of a component where an optimization led design process is applied in comparison to a computer aided design process.

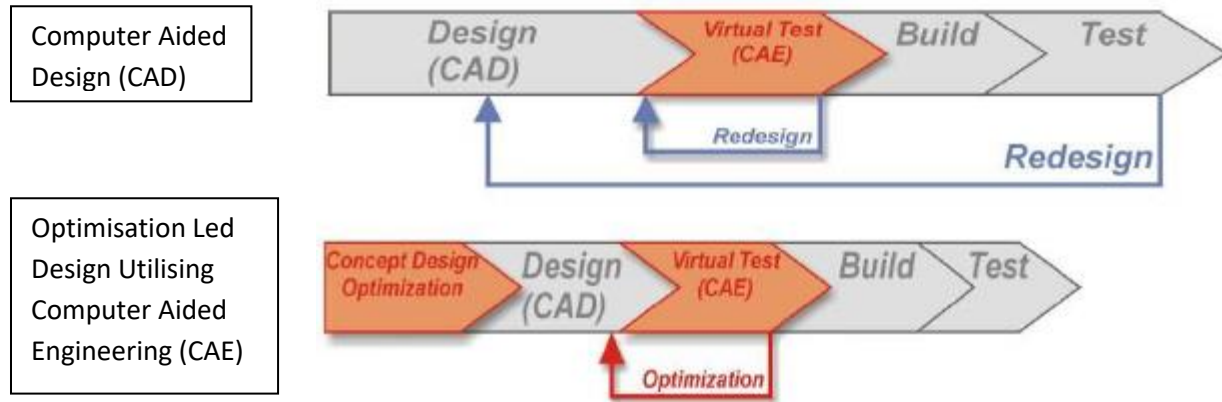


Figure 2. Comparison of CAD vs Optimisation Led Design (Adapted from Altair, 2018)

The manufacture of an optimised design is further considered in terms of the traditional manufacturing method, high pressure die casting, and utilising an additive manufacturing technique, selective laser melting, which allows closer alignment of the manufactured component to that of the optimized design. The application of additive manufacturing technologies also being of significant importance in the automotive industry (Attaran, 2017), where significant environmental savings are achievable both in the manufacturing process due to the reduction in raw materials required and the component closely meeting the ideal optimised specification.

2.0 Optimization

The optimization process is dependent first on establishing a finite element model with computer aided design software before analysis with computer aided engineering software where the consideration and application of appropriate variables, objectives and constraints are applied to the model. Each of which has a significant impact on the results of the optimization analysis.

2.1 Design Domain

The design domain is the volume which can be occupied by the component, where the component is required as part of a larger assembly careful consideration must be given to overall dimension and shape of the domain to avoid interference with other components. Figure 3 details an existing engine bracket design and the corresponding design domain for an application within a Hyundai vehicle.

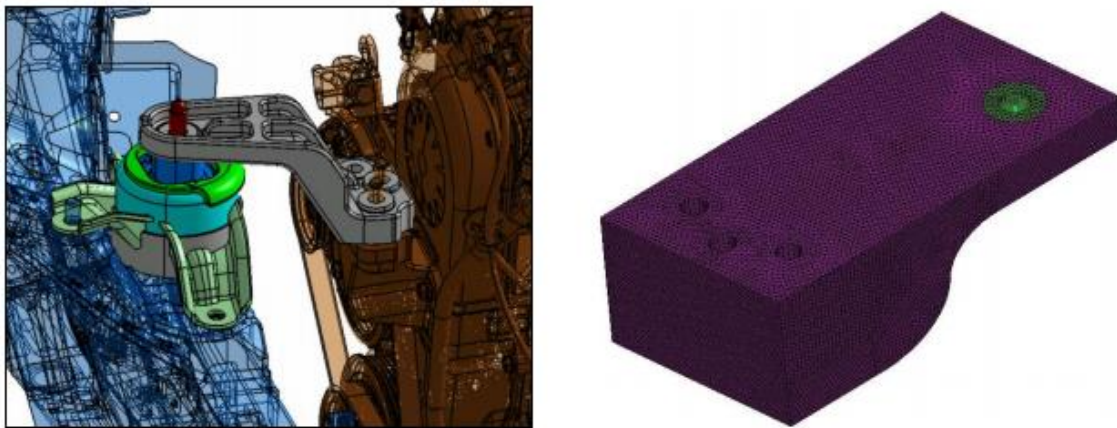


Figure 3. Existing engine bracket and corresponding domain designs (Sreedhar & Sasidhar, 2012)

The domain model also contains design and non-design regions, where the non-design regions are areas where no change can occur such as load bearing contact points and openings designed to receive fasteners of the bracket design specification. Figure 4 details non-design regions that have been specified on an existing jet engine bracket design prior to an optimization study, the dark blue and orange areas being the specified non-design regions, turquoise area available for design.

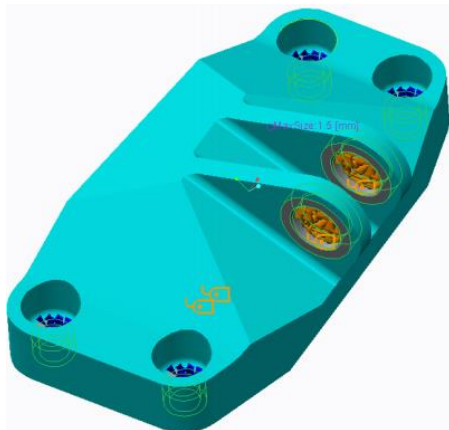


Figure 4. Design and non-design regions (CAESS, 2019)

A finite element mesh is generated within the domain using first order tetrahedral elements, over second order elements as these are more efficient in simple cases, the mesh density also being an important consideration. Where the change in average stress between elements is large, for example in cases where the stress is higher on the edges and surfaces the mesh size should be reduced to avoid problems in establishing the critical load paths.

To establish the load case for the model, forces and constraints are applied which reflect those specified in the design brief. The engine mounting bracket is likely to subject to several different load cases during the assembly of the vehicle and those under normally expected operation conditions. Where there are more than one load case present, Huebner, et al. (2001), suggest the weighted sum of load cases present is taken forward for the optimization analysis. And further suggest that load cases likely to be encountered by an engine bracket are;

- Drive off forward
- Drive off backwards
- Drive into a pothole
- Drive out of a pothole
- Transmission load
- Loads experienced during engine and vehicle assembly.

The bracket is expected to be rigidly fastened to the engine block and also the shock absorbing component transmitting the engine load to the vehicle chassis. The design domain inclusive of the non-design regions is subject to finite element analysis, with the non-design regions omitted from the following topology analysis.

2.2 Variables

Variables associated with the model design domain produced within the computer aided design environment can be specified as part of the optimization analysis which have a direct effect on the final design for manufacture, where material usage within the design domain normally being specified as 30% of the available volume. Such variables often determine how or if an optimised component design can be manufactured. As the existing engine mount is manufactured in a high pressure die casting process a single draw restraint is applied to ensure the finished component can be removed from the die on completion of the process. To avoid load path members being optimized to a size where manufacture becomes impracticable, a minimum member size constraint is specified.

The design domain and associated non-design regions are also considered as variables as these also have a direct bearing on the final design for manufacture, where an existing component is the subject of an optimization study the existing component dimensions and material of construction can be considered as a variable where appropriate.

2.3 Objectives

The objectives are the desired design specification which are the quantitative outcome of the optimization process. The objectives being measurable, against a minimum or maximum desired value. Typical objectives being displacement, stress, mass and frequency.

The objective for the engine mount bracket is considered as minimising the mass of the original design.

2.4 Constraints

The constraints are response limits specified during the optimization process which cannot be exceeded, where the calculated values are within the specified limits the optimized design is considered acceptable.

Typical constraints specified during optimization. Mass, where redesign of an existing component is considered this is expressed in terms of a percentage of the original mass, with 30% being a typical applied constraint. The limit of deflection within a plane or planes, limits of stress and strain, or frequency, imposed by the design specification or governing construction standard or code.

Stress and displacement constraints are applied to the engine mount bracket during the optimization analysis. Where the stress and displacement constraints being the maximum allowable under the component specification.

The single draw manufacturing variable can also be considered as a manufacturing constraint.

3.0 Optimization of the Engine Mount Bracket

The first optimization analysis will establish the major load paths utilising a topology study, followed by a shape optimization analysis. The order of analysis being important as discussed by Yildiz (2018), failure to consider the load paths at the concept stage will result in an optimization analysis that does not meet the design specification requirements.

Topology optimization analyses material distribution within a design domain, where high load bearing elements are assigned greater density than those bearing less load, by specifying the limit at which elements should be omitted from the design the critical load paths are identified. With 30% being a recognised default value in initial analysis (Altair, 2018).

Shape optimization takes the topology design based on the critical load paths and manipulates the outer boundaries to reduce stress concentration due to geometry, and also improve geometry and cross section to allow manufacture of the final design by traditional manufacturing methods (Altair, 2018).

The draw direction restraint applied has a significant influence on the final optimized design due to the impossible nature of manufacture of a fully optimised design utilising traditional methods.

The following graphics are reproduced from a paper on mounting bracket optimization by Sreedhar and Sasidhar (2012) concerning the optimization of an engine mount bracket associated with a Hyundai vehicle, the optimization process being clearly described. The major load paths are clearly visible in figure 5, where the topology analysis outcome has been set as an overlay of the original design domain (figure 3), of note are the non-design regions concerning the load bearing contact points and openings designed to receive fasteners, which are clear defined and visible in red.

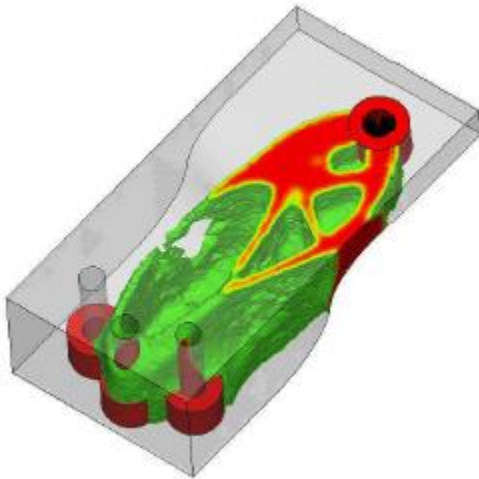


Figure 5. Topology analysis output engine mount bracket (Sreedhar & Sasidhar, 2012)

A further shape optimization analysis and consideration of manufacturing constraints in the final computer aided design for manufacture is detailed in figure 6. The minimum member size and manufacturing constraints visible in the final geometry.



Figure 6. Final optimized CAD manufacture engine mount bracket (Sreedhar & Sasidhar, 2012)

The optimization analysis completed by Sreedhar and Sasidhar (2012) reported a reduction in mass of 20% when compared with the original engine mount bracket design, whilst improving the stiffness. Studies completed by Paranthaman (2010), and Huebner (2001), reported similar reductions in mass, 23% and 31% respectively whilst maintaining stiffness, where an engine mount bracket was the subject of an optimization analysis.

The optimization analysis constraints and variables applied have a considerable effect on the final optimized design as illustrated in figure 7. Where an optimum design closely resembles the major load paths identified in the topology analysis, the resultant organic design presenting challenges in the manufacturing process where traditional techniques are employed.



Figure 7. Jet engine bracket model with varying constraints and variables applied (3Dprint, 2019)

4.0 Implementing Optimized Solution into Production

The manufacture of optimized design solutions can encounter physical restraints due to the manufacturing process utilised to form the component.

Draw direction restraints applied during manufacturing are shape controls which ensure that the component can be removed from the mould or die in which the component is formed. The parts of the mould or die must part cleanly along the draw plane avoiding negative angles in the component design (Solidthinking, 2015). As the engine mount is manufactured from aluminium in a high pressure die casting process the draw direction constraint therefore must be applied during the optimization process. Which often results in a component having fewer desirable characteristics than the optimum component where the draw direction constraint is not applied (Schramm, et al., 2002), this is seen in components which are predominantly under torsional loading where large hollow voids define the structure presented during optimization.

The utilisation of complex die assemblies incorporating movable side cores which allow the formation of under cuts (Custompartnet, 2019) go some way in allowing the optimized design to be successfully manufactured using tradition casting techniques, however the component still lacks the full potential of the optimized design.

The restrictions imposed by traditional manufacturing techniques such as casting, which is a formative process, can be offset by adopting additive manufacturing techniques in the manufacture of the component, ultimately allowing closer alignment of the manufactured component with that proposed by optimization analysis (Brackett, et al., 2011). Modern techniques such as selective laser melting can achieve similar mechanical properties of traditional techniques, but are highly dependant on the process and laser set up during the manufacturing process (Saadlaoui, et al., 2017). The process is also susceptible to distortion of the component and high levels of residual stress, which require further consideration during the optimization and manufacturing process to ensure the appropriate support and component density is achieved to minimise distortion and residual stress (Papadakis, et al., 2014).

Advances in optimization methods coupled with selective laser melting additive manufacturing techniques have further refined the manufacturing process, described in a study by Abdi, et al. (2018), where the optimization method Iso-XFEM and intuitive lattice structure design (isoline/isosurface performance criterion and eXtended Finite Element Method) is utilised. Figure 8 describes the improved optimized design of an automotive foot pedal incorporating an internal lattice structure.

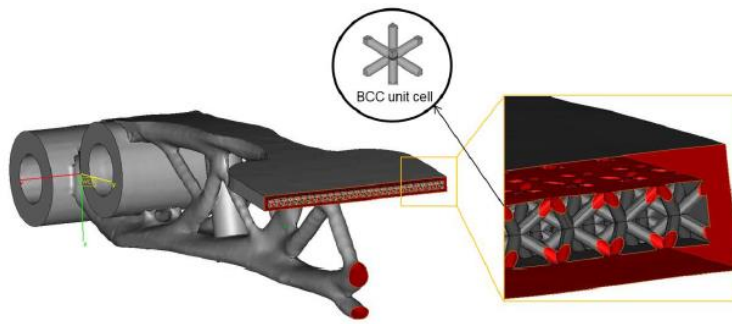


Figure 8. Lattice structure incorporated into automotive foot pedal design (Abdi, et al., 2018)

The optimized design presented by Abdi, et al. (2018), whitest increasing the thickness of section through the introduction of an internal lattice structure was found to have an overall increase in stiffness and reduction in von-misses stress when compared to an optimized solution provided by conventional methods. The finding support proposals made by Saadlaoui, et al. (2017) concerning the introduction of latticed structures within the manufactured component allowing closer alignment with simulation predictions.

5.0 Conclusion

The application of topology optimization in the design of components in the automotive industry has a significant benefit in reducing component weight and ultimately reducing fuel consumption and emissions. A typical high pressure die cast engine mount bracket was subject to a hypothetical topology optimization analysis, literature review found that in several separate studies weight reduction of between 20 and 31% was achievable where existing designs were subjected to analysis. Also, the mechanical properties were maintained or improved in some cases.

The optimization study consists of a topology analysis to establish the major load paths, followed by a shape analysis formulating a design based on the major load paths identified. Where mass minimisation is specified as an objective, maximum stress and displacement are considered as constraints in line with the original engine mount bracket specification. The optimised design conforming with the specified variables for domain space and non-design parts. The utilisation of a topology analysis study followed by a shape analysis are of critical importance in obtaining realistic results and an efficient design.

The full efficiencies in design available through optimization are restricted by traditional manufacturing processes due to manufacturing constraints applied. As an alternative an additive manufacturing technique, selective laser melting, was considered, where notable improvements in achieving the optimised design were found.

The application of topology optimisation in the design of engine mount brackets was found to meet and improve the design specification for the load cases considered.

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