

Comparing Various Multi-Disciplinary Optimization Approaches for Performance Enhancement and Weight Reduction of a Vehicle Chassis Frame

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ABSTRACT

Designing a vehicle chassis involves meeting numerous performance requirements related to various domains such as Durability, Crashworthiness and Noise-Vibration-Harshness (NVH) as well as reducing the overall weight of chassis. In conventional Computer Aided Engineering (CAE) process, experts from each domain work independently to improve the design based on their own domain knowledge which may result in sub-optimal or even non-acceptable designs for other domains. In addition, this may lead to increase in weight of chassis and also result in stretching the overall product development time and cost. Use of Multi-Disciplinary Optimization (MDO) approach to tackle these kind of problems is well documented in industry. However, how to effectively formulate an MDO study and how different MDO formulations affect results has not been touched upon in depth.

This study implements various MDO formulations on an established SUV chassis frame for further weight reduction and performance improvement. Results from different MDO formulations are compared and insights are provided into ways of formulating an MDO problem in order to achieve desired results. How the choice of optimization algorithm, number of objectives and constraints etc. affect MDO results is also discussed. 18 component thicknesses are selected based on domain understanding as design variables (DVs) for optimization. Various attributes/load-cases considered during optimization are -bending and torsional stiffness for Durability, global mode shapes from modal analysis for NVH, energy absorption and displacements at specific locations during frontal offset crash for crashworthiness. As a first step, a Design of Experiment (DoE) study is performed for each domain individually and results are analysed to identify conflicting targets. Response Surface (RSM) based optimization method is selected for optimization studies considering time and resource availability. Commercial software package, modeFRONTIER, is used as a process integration, design optimization and data analysis tool. Optimal designs from all MDO studies are compared with each other to evaluate effectiveness of formulations.

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INTRODUCTION

With vast increase in computing power, design of complex engineering systems such as automobiles is becoming increasingly computer centric. Designers are now able to capture system behaviors at greater depth and solve complex problems in a time bound manner which may not have been possible previously. Most of these systems have contributing factors from multiple disciplines or subsystems, often resulting in multiple conflicting objectives. Designers/Analysts always aim to optimize designs using formal/informal methods. Use of formal optimization techniques across various disciplines is also well known. As the complexity of systems increase, the need for system level collaborative optimization increases even more.

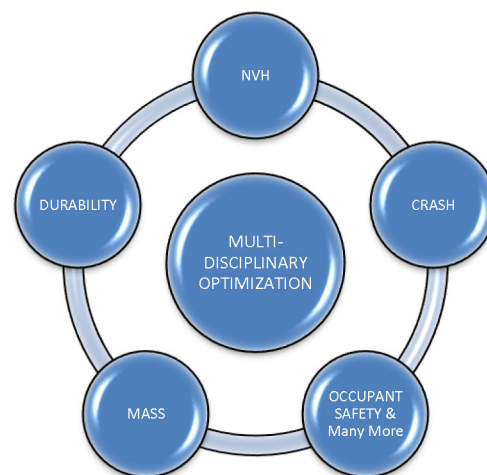


Figure 1. Multi-Disciplinary approach for automobiles

In the recent years Multi-Disciplinary Optimization (MDO) has emerged as a well-established optimization method as the computer speed increased, the simulation methodologies matured, and specialized MDO software tools have been developed. In MDO, designers aim to optimize all disciplines simultaneously as shown in [figure 1](#) rather than optimizing each discipline sequentially. It enables designers to find a solution which is optimum for all disciplines at the same time, hence reducing the computational efforts and time required during the entire design process. Various MDO techniques, such as, Collaborative Optimization (CO) [1], Analytical Target Cascading (ATC) [2], Concurrent Subspace Optimization (CSSO) [3], Bi-Level Integrated System Synthesis (BLISS) [4] etc. have been developed over the years. While these approaches have differences in the way they formulate and handle an MDO problem, all of them essentially target to capture interactions between various disciplines and produce optimum designs acceptable to all disciplines. While Gradient-Based optimization methods can be used for MDO studies, the evolutionary optimization techniques are more popular due to their ability to better handle complex problems and find global optimum solutions. Although MDO has a lot of advantages, there are still few challenges to make the use of the method widespread. Including all disciplines simultaneously, significantly increases the complexity of the problem. In an organization, getting experts from all disciplines to work together and compromise on individual disciplines to achieve greater system level optimum may prove to be a challenge in itself. Techniques such as surrogate based optimization have been developed to tackle such challenges. MDO is now a widespread method in automobile industry. Its application in fields such as crashworthiness, NVH and Durability is well documented in [5, 6, 7, 8, and 9].

PROBLEM DEFINITION

SUV chassis is taken for optimization study. [Figure 2](#) shows the chassis frame with selected members for optimization. Gauges of 18 structural members are selected and used as design variables in this study. Upper and lower limits have been decided by varying base thicknesses by $\pm 20\%$. Bending and torsional stiffness are selected from durability domain as these stiffness define the global performance of chassis. Frontal offset crash at chassis level is selected from crash domain. Untrimmed modal analysis is selected from NVH domain. Vertical bending, lateral bending, torsional and match box modes are selected as targets. Objective of this study is to compare MDO formulations with two objectives 1) Weight reduction while maintaining all performance targets at base level and 2) Performance improvement while maintaining mass at base level.

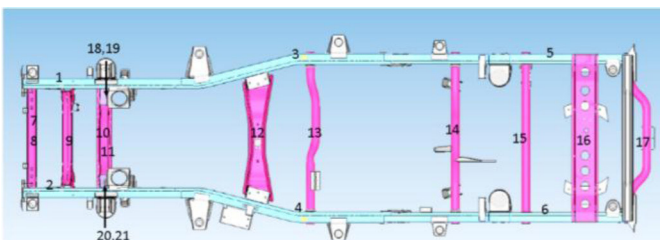


Fig. 2. Chassis Frame with design variables

METHODOLOGY

Response surface based optimization method is used in current work. Direct optimization based on solver results lead to large number of simulations and there is no control over the number of simulations required to converge to the global optima. Generally, for direct optimization, one needs to analyze results for optima after certain number of simulations and stop the optimization run if the satisfactory design is found. But this may lead to getting stuck at local optima most of the times. In RSM based optimization method, meta-models based on DOE matrices are created and used for optimization. Considering time, resources and non-linearity of problem, number of simulations for specific loadcase were decided. Commercial optimization software modeFRONTIER is used as a front end for process integration and optimization. Nastran is used for performing stiffness and modal analysis. LS Dyna explicit is used to evaluate crash loadcase.

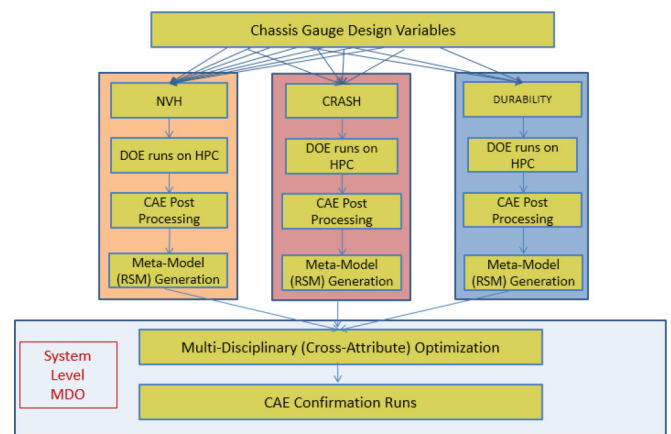


Figure 3. RSM based methodology for MDO

Crash Loadcase Set-Up

Performing the current MDO study on SUV chassis with full vehicle crash model requires lot of simulations involving huge run time and is very resource intensive with high server occupancy. Hence, to simplify and solve the problem within available resources of time and computational abilities, a representative set up for frontal offset deformable barrier (ODB) impact load case was considered. The chassis is set to impact against a stationary rigid wall with overlap matching with that during an offset crash at the full vehicle level. Thus loading conditions ([figure 4](#)) are replicated in the closest possible way ensuring chassis deformation ([figure 5](#)) to be similar to that observed during an offset impact.

Impact speed of the chassis is estimated on the basis of chassis energy absorption during full vehicle crash. Critical regions and components on chassis are tracked to measure deformations and energy absorption during the event which, in combination and independently, are set as objectives and constraints based on the MDO problem formulation.