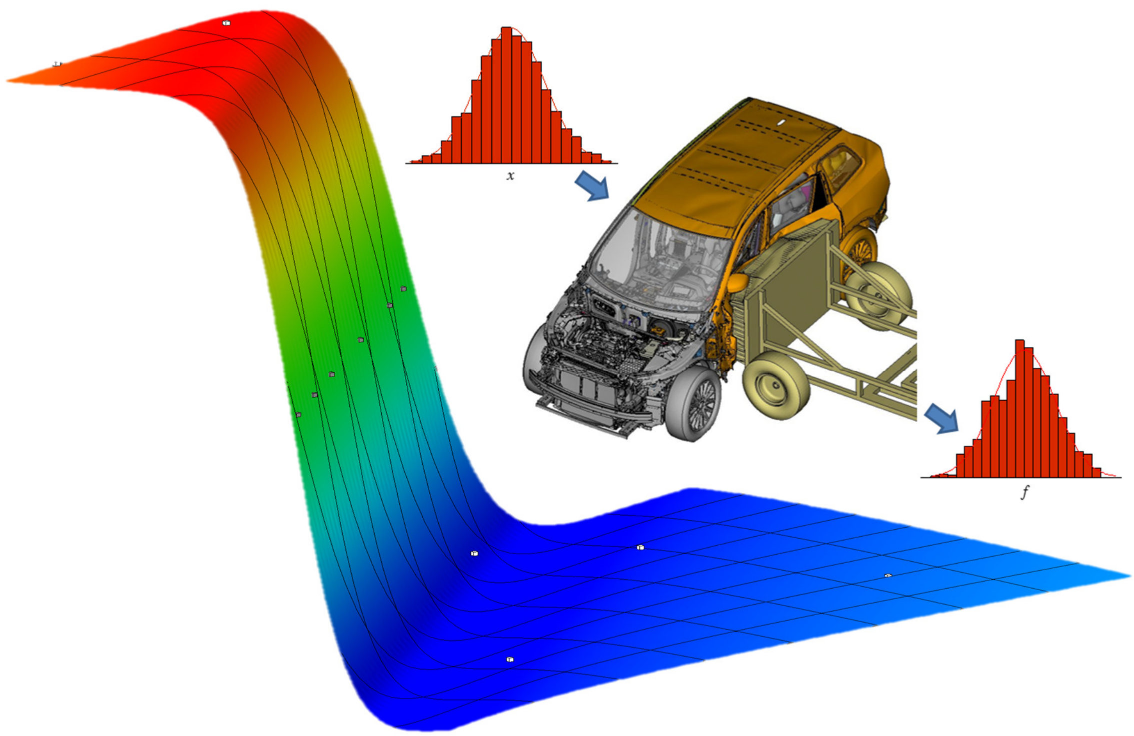
Robust and Multidisciplinary Design Optimization of Automotive Structures

Public report



Project within Trafiksäkerhet och automatiserade fordon - FFI
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Content

FFI in short

FFI is a partnership between the Swedish government and automotive industry for joint funding of research, innovation and development concentrating on Climate & Environment and Safety. FFI has R&D activities worth approx. €100 million per year, of which about €40 is governmental funding.

Currently there are five collaboration programs: Electronics, Software and Communication, Energy and Environment, Traffic Safety and Automated Vehicles, Sustainable Production, Efficient and Connected Transport systems.

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1. Summary

The automotive industry continuously strives to improve methods and processes in order to develop light-weight vehicles that meet new challenging requirements on emissions and safety. Optimization has been identified as a key enabler for further improvement. The primary aim of this project has been to find suitable methods for implementing large-scale robust and multidisciplinary design optimization of automotive structures within current product development. The work covers assessing existing methods and developing new improved ones, where needed. The methods are verified on small academic examples as well as large-scale industrial cases. The project is divided into two main parts and has resulted in two doctoral theses covering optimization of vehicle structures under uncertainty (Shetty, 2017) and metamodel-based multidisciplinary design optimization (MDO) of vehicle structures (Ryberg, 2017).

2. Sammanfattning på svenska

Bilindustrin strävar efter att kontinuerligt utveckla metoder och processer för att kunna konstruera fordon som uppfyller nya krav inom områdena miljö och säkerhet. Datorstödd optimering har identifierats som en viktig aktivitet att utveckla vidare. En stor utmaning är att kunna hantera de komplexa, tidskrävande och ofta multidisciplinära simuleringar som krävs. Det här projektet är ett samarbete mellan Linköpings universitet, Volvo Car Corporation och Combitech AB, med stöd från Altair Engineering AB, Enginsoft Nordic och Dynamore Nordic AB. Huvudsyftet är att hitta lämpliga metoder för att implementera storskalig robust och multidisciplinär optimering (MDO) av fordonsstrukturer inom dagens produktutveckling. Arbetet omfattar utvärdering av befintliga metoder och, vid behov, utveckling av nya förbättrade metoder. Metoderna verifieras både med mindre akademiska exempel och med storskaliga industriexempel. Projektet är indelat in i två delar som resulterat i var sin doktorsavhandling. Den första delen av projektet omfattar optimering med hänsyn till osäkerheter och beskriver en ny pragmatisk metod för icke-deterministisk strukturoptimering av storskaliga fordonsproblem. Arbetet omfattar även utvärdering av olika sätt att modellera materialvariationer. Den andra delen av projektet fokuserar på metoder för multidisciplinär optimering. Här beskrivs en metamodell-baserad metod lämplig för storskalig multidisciplinär optimering av fordonsstrukturer. Arbetet omfattar även utvärdering av olika metoder för att optimera antalet punktsvetsar i en bilkaross samt metoder att förbättra metamodellers noggrannhet. Vidare arbete bör nu fokusera på att applicera de föreslagna metoderna på nya lastfall och implementera dem i analysverktyg/mjukvaror.

3. Background

The development of vehicle structures comprises many different phases from early concept development to the final phase where the complete product is analysed. Optimization methods have a vital part in all these development phases. Methods and tools for optimization have developed significantly and an increasing number of industrial applications can be found in the literature. However, one major challenge is the complex, multidisciplinary, and often time-consuming simulations needed. Also the existence of highly non-linear responses is a major challenge. As a consequence meta-models are used to improve efficiency during optimization. Further, there is a need to support the development of robust and reliable engineering solutions.

Conclusions from previous research in "Robust Optimization and Multidisciplinary optimization of vehicle structures" [2009-00314] show that optimization is vital for the vehicle industry to be competitive with respect to shorter lead times, increased performance and lower weight and CO2 emissions. Optimization also contributes to increased understanding of systems and supports balancing of requirement. A description of the differences between MDO in the aerospace and automotive industries has been outlined and a process suitable for MDO of automotive structures that fits the development process and company organization has been presented. [View Licentiate thesis no. 1565, Linköping University.] Robust Optimization has been identified as critical to address structures which become more and more optimized. Potential methods and tools have been identified, and a description of how these can be integrated in the development process has been formulated. The result from the research shows that these methods have high potential in early development phases where the design freedom is higher. [View Licentiate thesis no. 1643, Linköping University.]

4. Purpose, research questions and method

The project has been divided into two main parts. The first part focusses on efficient stochastic optimization methodologies for large-scale engineering applications and the second part focusses on developing methodologies for performing multidisciplinary optimization of automotive structures.

The primary aim of the first part of the project has been to develop efficient stochastic optimization methodologies for large-scale engineering applications. Work has been conducted in three stages

- Identify and evaluate suitable, efficient, existing methods to perform stochastic analysis and stochastic design optimization of large-scale engineering structures.

- Develop new methodologies or modify existing methodologies to improve their performance and accuracy.

- Verify the capabilities of the developed methodologies using analytical examples and large-scale vehicle structural examples and compare their performance with traditional methods.

The second part focuses on topics associated with simultaneous optimization of aspects related to different disciplines or load cases. Also this part can be divided into three stages.

- Different solution methods for MDO are identified and evaluated. Based on the findings, a metamodel-based MDO process is proposed and illustrated by a thickness optimization with the objective to minimize mass.

- Different methods for reducing the number of spot welds in a structure are evaluated from a multidisciplinary point of view.

- The accuracy of metamodels is identified as one of the key enablers for successful MDO studies following the proposed MDO process. As a result, methods for improving metamodel accuracy for complex responses by the help of support vector machines are then studied

5. Objective

The primary aim of this project is to identify efficient methodologies for performing robust and multidisciplinary design optimization of vehicle structures, and ensure that the knowledge generated are implemented in the industrial usage.

Industrial objectives:

Implementation of MDO and robust optimization in the development process which:

- reduces the product development time.
- increases the ability to find weight-optimized design solutions.
- increases the ability to generate designs with robust characteristics.
- increases systems knowledge.

Increased collaboration with software development and implementation of research in the analysis and optimization software used in the industry.

Commercial goals:

Robust lightweight solutions with balanced properties increases the ability of the vehicle industry to be competitive in the market with products that meet customer and market demands in terms of environment (e.g. CO2, fuel consumption) and safety (e.g. robust crash performance, vehicle dynamics).

Academic goals:

- Develop and implement more efficient metamodels able of handling complex responses (e.g. bifurcations).
- Develop and implement models for handling of parameter variations and uncertainties (e.g. variation in high strength steel properties).
- Understanding of industrial challenges and needs.
- Implement methods that solve industrial problems.
- Go from academic examples to real industrial problems.
- Cooperate with national and international research environments on optimization-driven product development.
- Creating conditions for further research in this area.
- Publications in international research journals
- Presentations on conferences.
- Examination of two PhD´s.

6. Results and deliverables

In this Project, efficient methodologies and processes for performing non-deterministic optimization and multidisciplinary design optimization of large scale vehicle structural problems have been developed and verified using vehicle structural applications. The academic results from the project are presented in research articles and two doctoral theses and contribute to the fulfilment of the academic goals.

The presented methodologies will aid in developing light-weight vehicle structures without compromising performance, i.e. to achieve both safety requirements and emission targets. Performing optimization according to the presented methodologies will result in structures with robust crash behaviour, also from a multidisciplinary perspective.

Detailed results related to non-deterministic (robust) optimization methodologies are given in Sandeep Shetty's PhD thesis no. 1809, Linköping University. The main results are listed below.

- New pragmatic methods for non-deterministic optimization of large-scale vehicle structural problems have been developed.

- The methods developed are shown to be flexible, more efficient and reasonably accurate, which enables their implementation in the current automotive product development process.

- Developed methods have been verified using complex vehicle engineering application subjected multi-disciplinary load case.

- Since the material scatter modelling is critical for the accuracy of stochastic analysis results, in this work the accuracy of existing simplified material scatter modelling methods in representing real material property variations has been investigated.

Multidisciplinary design optimization and methods to improve metamodel accuracy are covered in Ann-Britt Ryberg's PhD thesis no. 1870 Linköping University. The main results are listed below.

- A description of a metamodel-based MDO-process suitable for large-scale optimization of automotive structures.

- A comparison of different methods for reducing the number of spot welds in an automotive body.

- Developed methods for improving metamodel accuracy for complex responses including discontinuities.

- Verified the proposed methods and processes on real-world automotive examples.

The project has resulted in exchange of information between the participating parties. The proposed methods are in the process of being implemented into the product development and will then contribute to the fulfilment of the commercial goals. Further, there is a potential to implement some of the proposed methods into the software delivered by some of the participating parties.

7. Dissemination and publications

7.1 Dissemination

How are the project results planned to be used and disseminated?	Mark with X	Comment
Increase knowledge in the field	X	
Be passed on to other advanced technological development projects		
Be passed on to product development projects	X	
Introduced on the market		
Used in investigations / regulatory / licensing / political decisions		

7.2 Publications

Ryberg, A.-B., Nilsson, L. (2016). Spot weld reduction methods for automotive structures. *Structural and Multidisciplinary Optimization* *53*(4):923-934. doi:10.1007/s00158-015-1355-4

Ryberg, A.-B., Nilsson, L. (2017). Improving metamodel accuracy for structural responses including discontinuities. *Accepted*.

Ryberg, A.-B., Nilsson, L. (2017). Improving accuracy of feedforward neural network metamodels for crashworthiness optimization. *To be submitted*.

Ryberg, A.-B. (2017). Metamodel-based multidisciplinary design optimization of automotive structures. Ph.D. thesis no. 1870. Division of Solid Mechanics, Linköping University. *In progress.*

Shetty, S., Nilsson, L. (2016). An evaluation of simple techniques to model the variation in strain hardening behavior of steel. *Structural and Multidisciplinary Optimization.* doi:10.1007/s00158-016-1547-6.

Shetty, S., Govik, A., Nilsson, L. (2016). Two sequential sampling methods for metamodeling in reliability-based design optimization. *Submitted.*

Shetty, S. (2017). Optimization of vehicle structures under uncertainties. Ph.D. thesis no. 1809. Division of Solid Mechanics, Linköping University.

8. Conclusions and future research

New improved methodologies to perform optimization under uncertainties and multi-disciplinary design optimization have been developed. These methods can handle complex vehicle structural problems encountered in the automotive industry and have been verified within the existing product development environment. Future work should focus on proceeding with implementation of the methodologies in the analysis tools and extend the application to other than the tested load cases.

9. Participating parties and contact persons

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