

# TOPOLOGY OPTIMIZATION IN AUTOMOTIVE BUMPER BEAM DESIGN

AZIZUL HILMI BIN HAJI AHMAD

This report is to be present as criteria to fulfill a part of bestowal stipulation for  
Bachelor's Degree in Mechanical Engineering (Design & Innovation)

Faculty of Mechanical Engineering  
Universiti Teknikal Malaysia Melaka

MAY 2008

‘I / we\* admit that have read this  
work and in opinion of me / we\* this work was  
adequate from the aspect scope and quality to the significance to awarded  
Bachelor Degree of Mechanical Engineering (Design & Innovation)’

Signature :.....  
Supervisor Name :.....  
Date :.....

Signature :.....  
Supervisor Name :.....  
Date :.....

“I admit this report is produce by my own except summary and passage which each of it  
I already notify the source”

Signature :.....

Writer name :.....

Date :.....

## ACKNOWLEDGEMENT

Alhamdulillah, with the name of Allah, with His blessing and generosity, I have finally completed this project successfully. I would like to take this opportunity to convey my thankfulness and appreciation to my projects supervisor, Mr. Mohd. Ruzi Bin Haji Harun for his excellent supervision, guidance, endeavor in making this project a triumph; as I gained a magnificent and valuable knowledge that no book would have written.

As well, I would also like to express my appreciation to the cooperation from the management of laboratory, especially the technicians in helping my experiment in the laboratory for their generous and enthusiastic help.

My greatest appreciation goes to my beloved family especially my father and mother for their encouragement, guidance and support upon me to go through this project. Also thanks to my brothers and sisters who support me in making this project successful.

## ABSTRAK

Sistem palang bumper automotif memainkan peranan penting bukan sahaja menyerap hentakan pelanggaran tetapi juga sebagai satu gaya reka bentuk. Banyak perhatian di dalam industri automotif telah difokuskan ke atas berat, keselamatan dan juga pengurangan penggunaan bahan sejak bertahun-tahun kebelakangan ini berdasarkan reka bentuk pengoptimuman. Teknik pengoptimuman topologi digunakan dalam mengoptimumkan rekabentuk palang bumper. Untuk projek ini, palang bumper Perodua Myvi telah dipilih sebagai kes kajian. Gambaran keseluruhan prosedur pengoptimuman topologi dan sesetengah perkara berkaitan dalam industri automotif berkaitan reka bentuk palang bumper dijelaskan dengan teliti dalam laporan ini. Reka bentuk palang bumper telah dioptimumkan berdasarkan teknik pengoptimuman topologi dan hasilnya empat rekabentuk konsep telah dibangunkan menggunakan perisian SolidWorks. Kemudian rekabentuk yang telah dioptimumkan dianalisis berdasarkan prestasi impak palang bumper menggunakan perisian analisis COSMOSWORKS Designer. Setelah dianalisis, keputusan analisis bagi setiap reka bentuk konsep tersebut dibandingkan untuk memilih reka bentuk optimum yang terbaik berdasarkan kajian optimum yang mangandungi fungsi objektif, perubahan reka bentuk dan kekangan. Daripada kajian ini didapati reka bentuk konsep 2 adalah reka bentuk optimum yang terbaik kerana ia memenuhi kriteria-kriteria kajian optimum tersebut. Akhir skali, penggunaan pengoptimuman topologi sepanjang proses pembangunan palang bumper automotif dibincangkan, termasuk mengenalpasti kebaikannya.

## ABSTRACT

Automotive bumper beam system plays a very important role not only absorbing impact energy but also in a styling stand point. A great deal of attention within the automotive industry has been focused upon light weight, sufficient safety and also less material used in recent years based on optimization design. Topology optimization technique was used to optimize bumper beam design. For this project Perodua Myvi bumper beam was selected as the case study. An overview of topology optimization procedure and some closely related subjects in automobile industry focused on bumper beam design explained in details in this report. The bumper beam design was optimized base on topology optimization technique and the outcome is four concept design were developed using SolidWorks software. The optimized design then analyze regarding the impact performance using COSMOSWORKS Designer analysis software. From the analysis results then the four design concept have been compared to select the best optimized design base on the optimization study which defined by objective function, design variable and constraints. It was found that design concept 2 is the best optimized design because it fulfills the optimized study criteria. Finally, the application of topology optimization during the development process of an automotive bumper beam is discussed, including identification of its major benefits.

## TABLE OF CONTENT

CHAPTER	TOPIC	PAGE
	CONFESSION	II
	ACKNOWLEDGEMENT	III
	ABSTRAK	IV
	ABSTRACT	V
	TABBLE OF CONTENTS	VI
	LIST OF FIGURES	XI
	LIST OF TABLES	XIII
	LIST OF ABBREVIATIONS AND SYMBOLS	XIV
<b>CHAPTER 1</b>	<b>INTRODUCTION</b>	<b>1</b>
	1.1 Project Background	1
	1.2 Problem Statement	1
	1.3 Objectives of Project	2
	1.4 Scopes of Project	2
	1.5 Project Flow Chart	3
	1.6 Significant of Project	4

1.7	Summary	4
<b>CHAPTER 2</b>	<b>LITERATURE REVIEW</b>	<b>5</b>
2.1	Introduction	5
2.2	Topology Optimization	5
	2.2.1 Topology Optimization Applications	7
2.3	Computer Aided Engineering (CAE)	8
	2.3.1 CAE Tools	8
	2.3.2 CAE Applications	9
	2.3.3 CAE In Auto Industry	10
	2.2.4 COSMOSWORKS Software	11
	2.3.5 Advantages of CAE	13
2.4	Computer Aided Design (CAD)	14
	2.4.1 Software	15
	2.4.2 Applications of CAD	16
	2.4.3 Software Technologies	17
	2.4.4 Hardware And OS Technologies	18
	2.4.5 The CAD Operator	18
	2.4.6 Advantages of CAD	20
	2.4.7 Disadvantages of CAD	21
2.5	Rapid Prototyping (RP)	22
	2.5.1 Types of RP Machine	22
	2.5.2 RP Application	23
	2.5.3 Advantages of RP	23
	2.5.4 Disadvantages of RP	23
2.6	Automotive Bumper Beam	25
2.7	Summary	28
<b>CHAPTER 3</b>	<b>TOPOLOGY OPTIMIZATION</b>	<b>29</b>
3.1	Introduction	29



3.2	Method	31
	3.2.1 Mathematical Programming Method	31
	3.2.2 Optimum Criteria Method	32
	3.2.3 Product Development Cycles Method	33
3.3	Summary	35
<b>CHAPTER 4</b>	<b>METHODOLOGY</b>	<b>36</b>
4.1	Introduction	36
4.2	Literature Search	38
4.3	Develop Concept in 2D Topology Optimization Procedure	38
	4.3.1 Defining and Running The Initial Studies	40
	4.3.2 Evaluating The Results of Initial Studies	40
	4.3.3 Defining The Optimization Study	41
4.4	Refine 2D Concept into 3D Modeling	41
4.5	Investigate and Analyze The Impact Performance of Bumper Beam	42
4.7	Summary	43
<b>CHAPTER 5</b>	<b>DETAIL DESIGN</b>	<b>44</b>
5.1	Introduction	44
5.2	Original Design	45
	5.2.1 Design Specification	46
	5.2.2 Material	46
5.3	Design Concept 1	48
	5.3.1 Design Specification	49
	5.3.2 Material	49
5.4	Design Concept 2	50

	5.4.1 Design Specification	51
	5.4.2 Material	51
5.5	Design Concept 3	52
	5.5.1 Design Specification	53
	5.5.2 Material	53
5.6	Design Concept 4	54
	5.6.1 Design Specification	55
	5.6.2 Material	55
5.7	Summary	56
<b>CHAPTER 6</b>	<b>RESULTS</b>	<b>57</b>
6.1	Introduction	57
6.2	Analysis	57
	6.2.1 Analysis Procedures	59
6.3	Results Analysis	63
	6.3.1 Materials	63
	6.3.2 Load & Restraints Information	64
	6.3.3 Mesh	64
	6.3.4 Stress, Displacement and Strain Results	68
6.4	Summary	74
<b>CHAPTER 7</b>	<b>DISCUSSION</b>	<b>75</b>
7.1	Introduction	75
7.2	Design Comparison	75
7.3	Summary	80
<b>CHAPTER 8</b>	<b>CONCLUSION &amp; RECOMMENDATION</b>	<b>81</b>
8.1	Conclusion	81
8.2	Recommendation	82

<b>REFERENCES</b>	<b>83</b>
<b>APPENDICES</b>	<b>85</b>

## LIST OF FIGURES

FIGURE	TITLE	PAGE
1.1	Project Flow Chart	4
2.1	Topology Optimization	7
2.2	Design Configuration of Topology Optimization	7
2.3	An Example of CAE Software	11
2.4	Elements model	13
2.5	Element nodes	13
2.6	CAD Development Process	15
2.7	An Example of CAD Software	16
2.8	3D CAD Model	17
2.9	An Example of CAD Engineering Drawing	20
2.10	Automotive Bumper Beam System	26
2.11	An Example of Bumper Crash Simulation	27
3.1	Topology Optimization Process	31
4.1	Method Flow Chart	38
4.2	Topology Optimization Procedures	40
4.3	Bumper beam impact test based on Euro NCAP	43
5.1	Perodua Myvi bumper beam	45
5.2	Bumper beam 3D CAD model using SolidWorks 2007	46
5.3	Bumper beam detail design	47
5.4	Material specifications (source from SolidWorks 2007)	48
5.5	Bumper beam design concept 1	49

5.6	Bumper beam concept 1 detail design	50
5.7	Bumper beam design concept 2	51
5.8	Bumper beam concept 2 detail design	52
5.9	Bumper beam design concept 3	53
5.10	Bumper beam concept 3 detail design	54
5.11	Bumper beam design concept 4	55
5.12	Bumper beam concept 1 detail design	56
6.1	The bumper beam impact test simulation	59
6.2	Restraint is set in the COSMOSWORKS Designer	60
6.3	Force is set in the COSMOSWORKS Designer	61
6.4	Setting the mesh	61
6.5	Meshing result	62
6.6	The impact analysis is running in the COSMOSWOKS Designer	62
6.7	Stress, displacement and strain results	63
6.8	Stress graph for the original bumper beam design	68
6.9	Displacement graph for the original bumper beam	70
6.10	Strain graph for original bumper beam	72
7.1	Mass vs. design graph	76
7.2	Min stress vs. design graph	77
7.3	Max stress vs. design graph	78

**LIST OF TABLES**

<b>TABLE</b>	<b>TITLE</b>	<b>PAGE</b>
6.1	Materials results	64
6.2	Restraint and load information	64
6.3	Original design mesh information	65
6.4	Design concept 1 mesh information	65
6.5	Design concept 2 mesh information	66
6.6	Design concept 3 mesh information	66
6.7	Design concept 4 mesh information	67
6.8	Stress results table	69
6.9	Displacement results table	71
6.10	Strain results table	73
7.1	Bumper beam thickness comparison	76
7.2	Bumper beam mass comparison	76
7.3	Bumper beam stress limit	77

**LIST OF ABBREVIATIONS AND SYMBOLS**

<b>SYMBOL</b>	<b>DEFINITION</b>
PSM	Projek Sarjana Muda
UTeM	Universiti Teknikal Malaysia Melaka
FKM	Fakulti Kejuruteraan Mekanikal
CAD	Computer Aided Design
CAE	Computer Aided Engineering
RP	Rapid Prototyping
FEA	Finite Element Analysis
FEM	Finite Element Method
CFD	Computational Fluid Dynamics
MES	Mechanical Event Simulation
SLA	Stereolithography Apparatus
3DP	Three-Dimensional Printing
FDM	Fused Deposition Modeling

## CHAPTER 1

### INTRODUCTION

#### 1.1 Project Background

This project will focus on how to produce innovative design of automotive bumper beam using topology optimization procedure. The project will start from studying the topology optimization in detail that will be applied in designing automotive bumper beam. Then generate conceptual design using Computer Aided Design (CAD) software and develop the concept in 2D topology optimization procedure and lastly, investigate and analyze the impact performance of bumper beam using COSMOSWORKS Designer software.

Since the topology optimization procedure in especially in automotive development industry is still new in UTeM, the project was chosen to expose the application of this process to all students in UTeM especially the mechanical engineering student. This project also describes the advantages and disadvantages using this procedure.

#### 1.2 Problem Statement

Fuel price increase situation currently increasingly onerous vehicle consumer. Various state-of-the-art technologies to the car were created in order to reduce fuel



consumption without effect the performance of the car itself. One of the aspects is reducing the weight of the car because the more weight of the car the more fuel per kilometer is used. Thus, in this case study I will focus on designing lighter car bumper beam using topology optimization procedure. The optimized bumper beam design that will improved fuel economy and performance of a car.

Topology optimization procedure in automotive industry is still new in UTeM and students here are not familiar with this process. Students also did not know the capability of this kind of method in producing the most optimize design in the beginning of product design development process with shorter lead time by using the applicable CAE software. Furthermore, the using of the Computer Aided Engineering (CAE) optimization software among UTeM's students is quite rare.

### **1.3 Objectives of Project**

The objectives of the project are:

- a) To produce innovative design of automotive bumper beam using topology optimization method focused on Perodua Myvi bumper beam.
- b) Design lighter bumper beam that will improved fuel economy and performance of a car.

### **1.4 Scopes of Project**

The scopes of the project are:

- a) To study the topology optimization.
- b) To generate conceptual design using CAD software.
- c) To develop concept in 2D topology optimization procedure.

- d) To refine 2D concept into 3D modeling using solid modeling software.
- e) To investigate and analyze the impact performance of bumper beam using COSMOSWORKS Designer software.

## 1.5 Project Flow Chart

Figure 1.1 shows the project flow chart for PSM 1 and PSM 2:

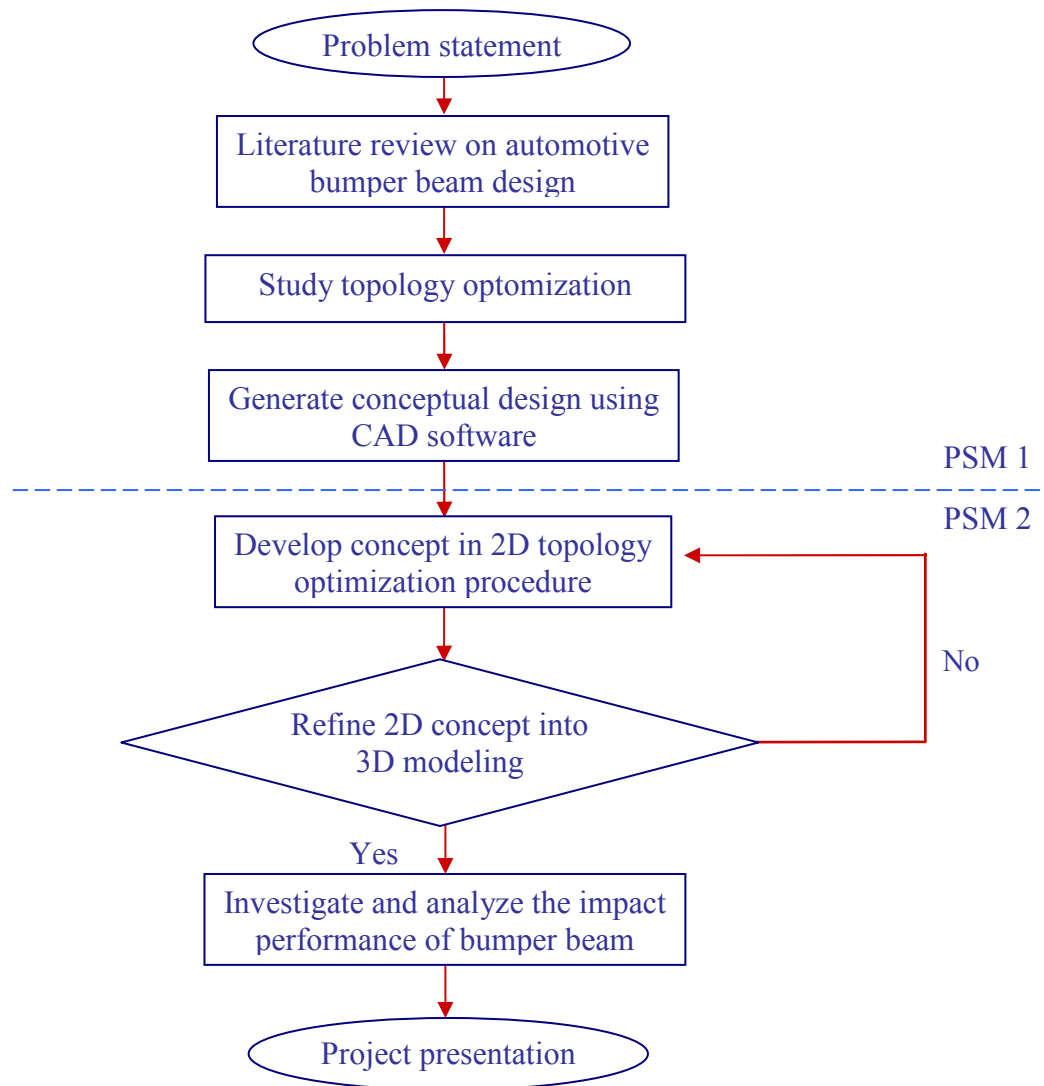


Figure 1.1 Project flow chart

## **1.6 Significant of Project**

To see the potential of this topology optimization procedure, an automotive bumper beam was selected for this project. The development concept of the bumper beam will be done in 2D topology optimization procedure using CAD optimization software. Then, from the 3D modeling concept, investigate and analyze the impact performance of bumper beam using COSMOSWORKS Designer software.

## **1.7 Summary**

Thus, hopefully this report will be reference to the UTeM's mechanical student about the important and capability of using this topology optimization method especially in automotive development.

## CHAPTER 2

### LITERATURE REVIEW

#### 2.1 Introduction

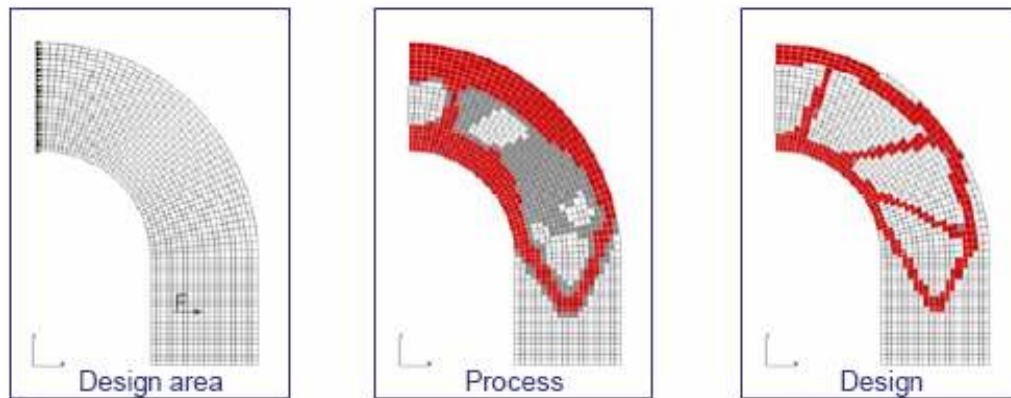
In this chapter explain in details about all topics that related in this project. The subject that will be covered are topology optimization, automotive bumper beam, computer aided design (CAD), computer aided engineering (CAE), rapid prototyping (RP) and automotive bumper beam.

#### 2.2 Topology Optimization

One of the important modifications that could greatly influence the overall automotive frame or structure performance while reducing mass is optimization analyses. Successive optimization analyses would be performed to determine the optimal architecture, gauges, section sizes and shapes. Finite element-based structural analyses and optimization software tools would be used to design and optimize structures.

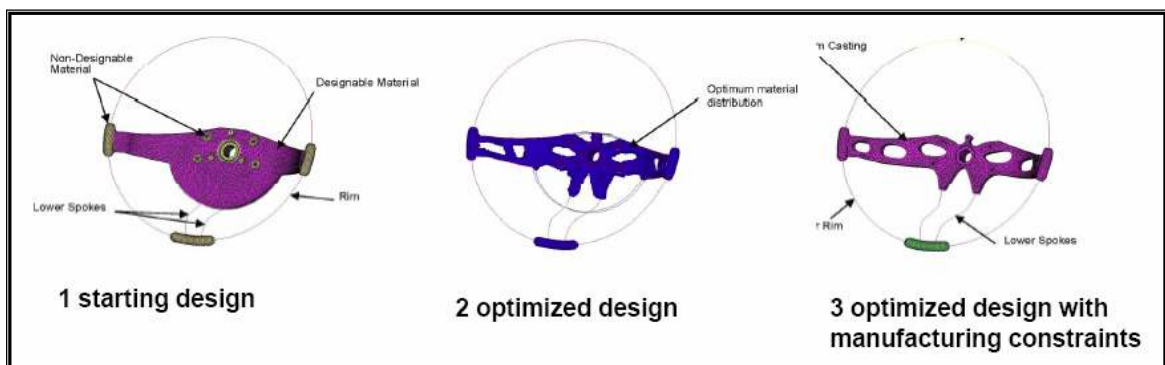
One type of the optimization analyses is topology optimization. Topology optimization generates an optimal material distribution for a set of loads and constraints within a given design space. The design space can be defined using shell elements, solid elements, or both. In the classical topology optimization setup, global loads and boundary conditions are applied to acquire the load paths (i.e., optimal design structure)

by solving the minimum compliance problem. Manufacturing constraints can also be imposed using minimum member size and draw direction constraints [3]. **Figure 2.1** shows the basic process of topology optimization.



**Figure 2.1** Topology optimization

Topology optimization is the latest type of optimization for the area of mechanically loaded components. With topology optimization structural parts are identified which do not contribute to the components behavior. In other words, in given design space material is distributed in such a way that under certain constraints specific objectives are met. **Figure 2.2** illustrates on the design configuration of topology optimization.



**Figure 2.2** Design configuration of topology optimization

### 2.2.1 Topology Optimization Applications

Currently, there are three main fields where topology optimization is applied:

- a) The very early design phase, where the design can easily be changed. Here the topology optimization starts from a rough design proposal.
- b) When potential for reducing the components stresses and weight needs to be identified. Here the topology optimization starts from an already existing design model.
- c) When parts of an already existing structure are completely redesign.

## **2.3 Computer Aided Engineering (CAE)**

Computer-aided engineering (often referred to as CAE) is any use of computer software to solve engineering problems. In addition, CAE is the application of computer software in engineering to analyze the robustness and performance of components and assemblies. It encompasses simulation, validation and optimization of products and manufacturing tools. With the improvement of graphics displays, engineering workstations, and graphics standards, CAE has come to mean the computer solution of engineering problems with the assistance of interactive computer graphics.

CAE software is used on various types of computers, such as mainframes and superminis, engineering workstations, and even personal computers. The choice of a computer system is frequently dictated by the computing power required for the CAE application or the level (and speed) of graphics interaction desired. The trend is toward more use of engineering workstations, especially a new type known as supergraphics workstations [13].

### **2.3.1 CAE Tools**

Considering information technology that provides tools and techniques to help in design and manufacturing support, the tools used are considered CAE tools. Design engineers use a variety of CAE tools, including large, general-purpose commercial programs and many specialized programs written in-house or elsewhere in the industry. Solution of a single engineering problem frequently requires the application of several CAE tools. Communication of data between these software tools presents a challenge for most applications. Data are usually passed through proprietary neutral file formats, data interchange standards, or a system database.

A typical CAE program is made up of a number of mathematical models encoded by algorithms written in a programming language. The natural phenomena being analyzed are represented by an engineering model. The physical configuration is described by a geometric model. The results, together with the geometry, are made visible via a user interface on the display device and a rendering model (graphics image).

In the future CAE systems will be major providers of information to help support design teams in decision making. In regards to information networks, CAE systems are individually considered a single node on a total information network and each node may interact with other nodes on the network [13].

### **2.3.2 CAE Applications**

CAE areas covered include:

- a) Stress analysis on components and assemblies using FEA (Finite Element Analysis).
- b) Thermal and fluid flow analysis Computational fluid dynamics (CFD).
- c) Kinematics.
- d) Mechanical event simulation (MES).
- e) Behavioral Modeling (BMX).
- f) Analysis tools for process simulation for operations such as casting, molding, and die press forming.
- g) Optimization of the product or process.

In general, there are three phases in any computer-aided engineering task:

- a) Pre-processing – defining the model and environmental factors to be applied to it. (typically a finite element model, but facet, voxel and thin sheet methods are also used).