Normal Frequency Analysis of a Vehicle Chassis and Design Optimization

By:

MS.ME Ahmad A. Abbas

Sr. Analysis Engineer

Ahmad.Abbas@AdvancedCAE.com

www.AdvancedCAE.com

March 25, 2008

Table of Contents

Project objective 4
Introduction 5
Analysis Information 6
  Original Model Geometry 6
  Material Properties 7
Results for original modal 8
Modification of the original structure 11
Results of the Modified Modal 14
Model Verification 17
Discussion and Conclusion 18
References 19

Table of Illustrations

FIGURE 1 VEHICLE MODEL MESH 4
FIGURE 2 MODES OF VIBRATION FOR A SIMPLY SUPPORTED BEAM 5
FIGURE 3 THE ORIGINAL MODEL OF THE FRAME 6
FIGURE 4 MAXIMUM DEFORMATION AT MODE 7 OF THE ORIGINAL MODEL.... 9
FIGURE 5 MAXIMUM ELEMENT STRAIN ENERGY AT MODE 7 OF THE ORIGINAL MODEL 9
FIGURE 6 MAXIMUM ELEMENT STRESS AT MODE 7 OF THE ORIGINAL MODEL.... 9
FIGURE 7 MAXIMUM DEFORMATION AT MODE 8 OF THE ORIGINAL MODEL.... 10
FIGURE 8 MAXIMUM DEFORMATION AT MODE 9 OF THE ORIGINAL MODEL.... 10
FIGURE 9 MAXIMUM ELEMENT STRAIN ENERGY AT MODE 7 IN THE ORIGINAL STRUCTURE 11
FIGURE 10 MAXIMUM ELEMENT STRESS AT MODE 7 IN THE ORIGINAL STRUCTURE 12
FIGURE 11 COMPONENTS SHOWN IN WHITE WILL BE UPDATED 13
FIGURE 12 MAXIMUM DEFORMATION AT MODE 7 OF THE MODIFIED MODEL.... 15
FIGURE 13 MAXIMUM ELEMENT STRAIN ENERGY AT MODE 7 OF THE MODIFIED MODEL.... 15
FIGURE 14 MAXIMUM ELEMENT STRESS AT MODE 7 OF THE MODIFIED MODEL.... 15
FIGURE 15 MAXIMUM DEFORMATION AT MODE 9 OF THE MODIFIED MODEL.... 16
FIGURE 16 MAXIMUM DEFORMATION AT MODE 9 OF THE MODIFIED MODEL.... 16

Index of Tables

TABLE 1 ALLOY STEEL AISI NUMBER 1015 MECHANICAL PROPERTIES 7
TABLE 2 THICKNESS MODIFICATION TABLE 13

Project objective

For a given vehicle structure it is required to enhance the structure rigidity for NVH and performance consideration, thus find the normal modal frequency response for spanning frequencies of 0 to 50 Hz and then optimize the design to increase the 7th vibration mode by 1 or more Hz.

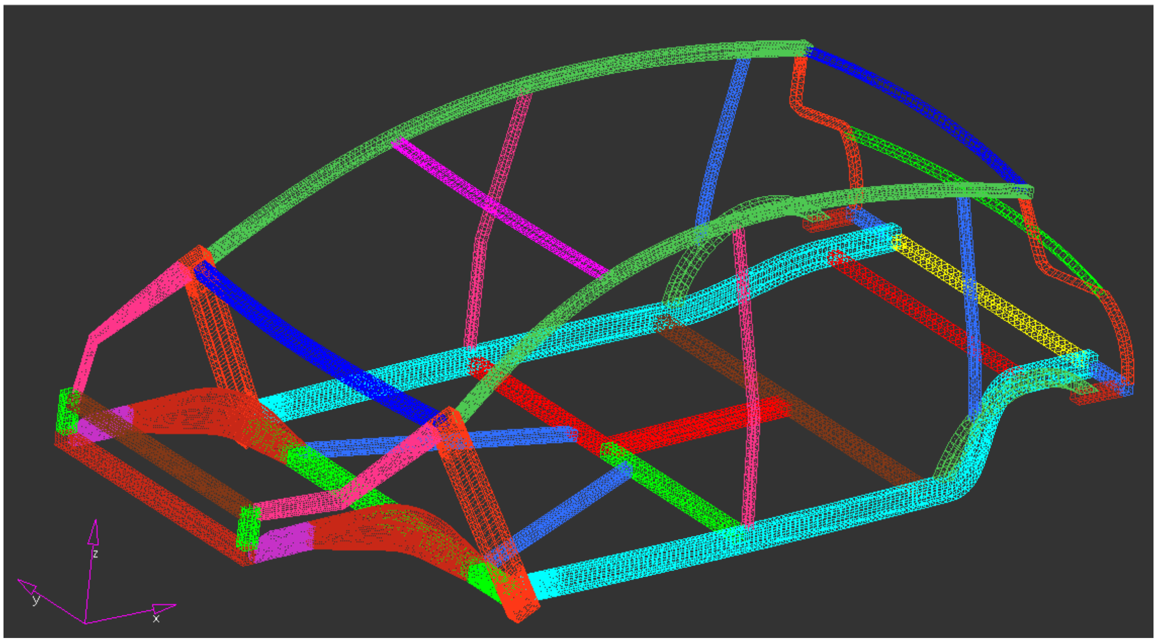

Figure 1 Vehicle model mesh

Introduction

A normal mode of a structural system is a pattern of motion in which all parts of the system move sinusoidally with the same frequency and in phase. The frequencies of the normal modes of a system are known as its natural frequencies or resonant frequencies. A vehicle chassis has a set of normal modes that depend on its structure, materials and boundary conditions.

Looking at the governing equation of motion for the given frame

$$[M]\ddot{x}+[C]\dot{x}+[K]x=0$$

Where; [M], [C], and [K] are the mass, damping and stiffness structure related matrices; then upon ignoring the damping effect one would rewrite equation as:

$$[M]\ddot{x}+[K]x=0$$

Solving the second order deferential we get:

$$\{x\}=\{\phi\}e^{i\omega t}$$

Where [ω] is the natural frequency, characteristic frequency, also known by the fundamental frequency of the fame under analysis.

$$\det([K]-\omega^2[M])=0$$

The eigenvector associated with the natural frequency is called the normal mode or what is known by the mode shape of the system, where the normal mode corresponds to the deflected shape patterns of the structure. For a simply supported beam the modes of vibration are as following:

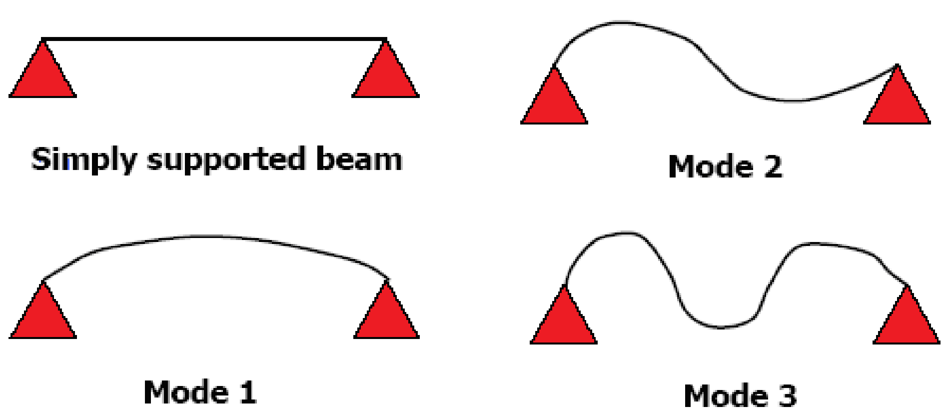

Figure 2 Modes of vibration for a simply supported beam

Analysis Information

Original Model Geometry

The original model shown in Figure 3 is a typical vehicle frame with various thicknesses.

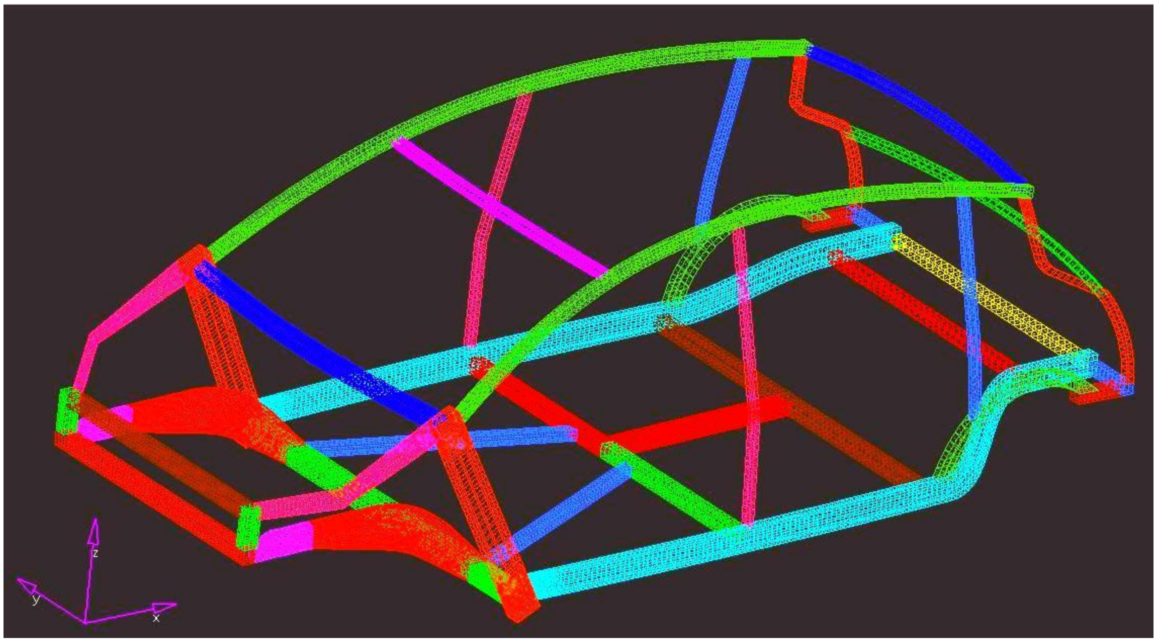

Figure 3 The original model of the frame

Material Properties

As specified the frame was modeled using the one main isotropic material in the component assembly, the main to material is alloy steel AISI number 1015.

Alloy steel AISI number 1015	
Density:	**7300 kg/m^3**
Elastic Modulus:	**207 GPa**
Poisson's Ratio:	**0.3102**
Tensile Strength:	**420.6 MPa**
Yield Strength	**313.7 MPa**
Percent Elongation:	**39 %**

Table 1 Alloy steel AISI number 1015 mechanical properties

Results for original modal

Normal mode frequencies displacement, strain and stress results

Mode: 1
Freq: 0.636E-03 Hz

- Maximum deformation is 7.51.
- Maximum element strain energy density is 0.228E-10.

Mode: 2
Freq: 0.639E-03 Hz

- Maximum deformation is 7.24.
- Maximum element strain energy density is 0.487E-09

Mode: 3
Freq: 0.812E-03 Hz

- Maximum deformation is 6.19.
- Maximum element strain energy density is 0.126E-09.

Mode: 4
Freq: 0.881E-03 Hz

- Maximum deformation is 6.64.
- Maximum element strain energy density is 0.671E-10.

Mode: 5
Freq: 0.889E-03 Hz

- Maximum deformation is 5.98.
- Maximum element strain energy density is 0.318E-10.

Mode: 6
Freq: 0.936E-03 Hz

- Maximum deformation is 7.30.
- Maximum element strain energy density is 0.220E-10.

Mode: **7**
Freq: 17.1 Hz

- Maximum deformation is 7.69.
- Maximum element strain energy density is 0.353E-01.

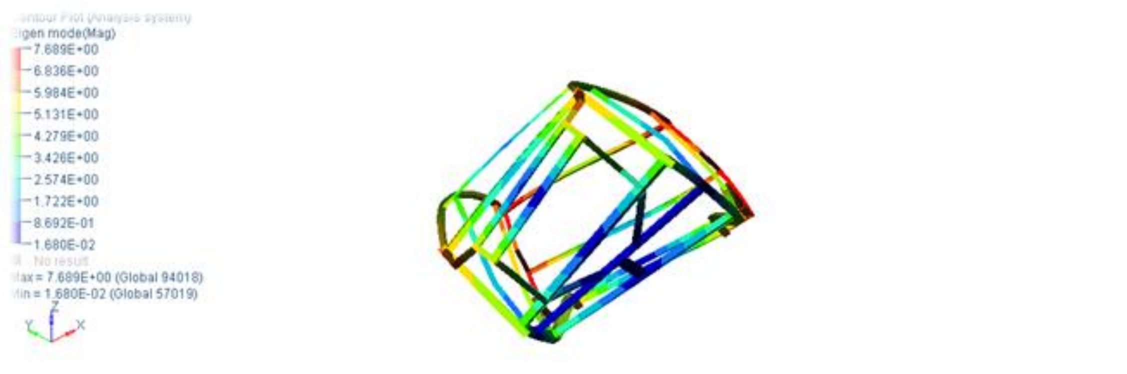

Figure 4 Maximum deformation at mode 7 of the original model

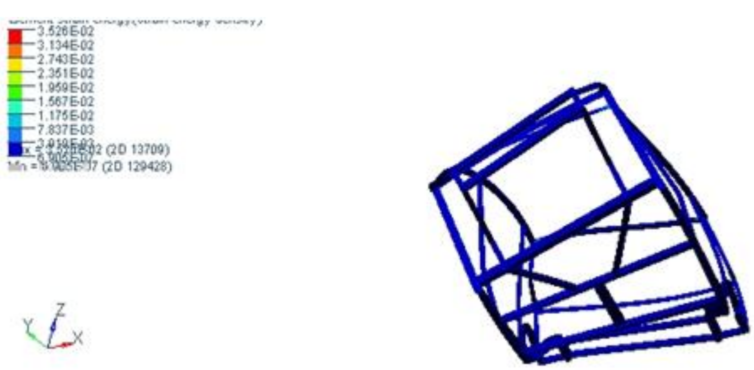

Figure 5 Maximum element strain energy at mode 7 of the original model

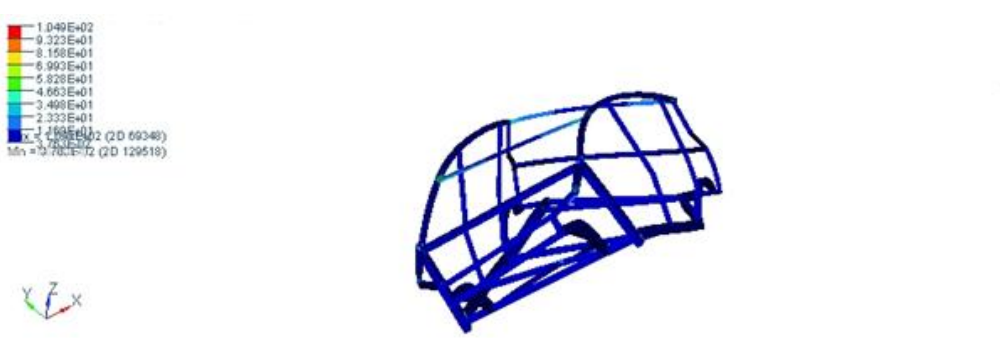

Figure 6 Maximum element stress at mode 7 of the original model

Mode: 8
Freq: 21.4 Hz

- Maximum deformation is 10.9.
- Maximum element strain energy density is 0.934E-01.

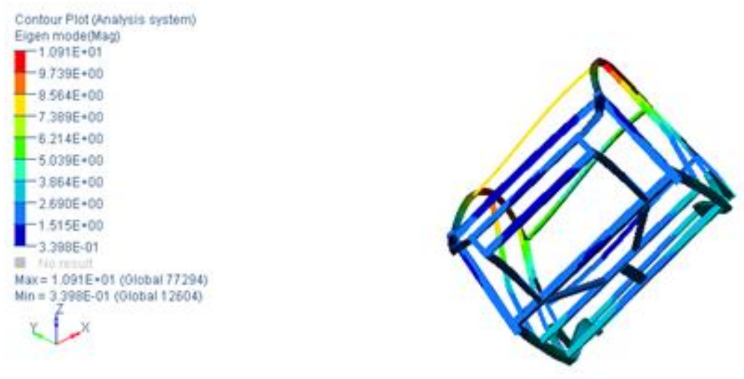

Figure 7 Maximum deformation at mode 8 of the original model

Mode: 9
Freq: 28.8 Hz

- Maximum deformation is 8.31.
- Maximum element strain energy density is 0.904E-01.

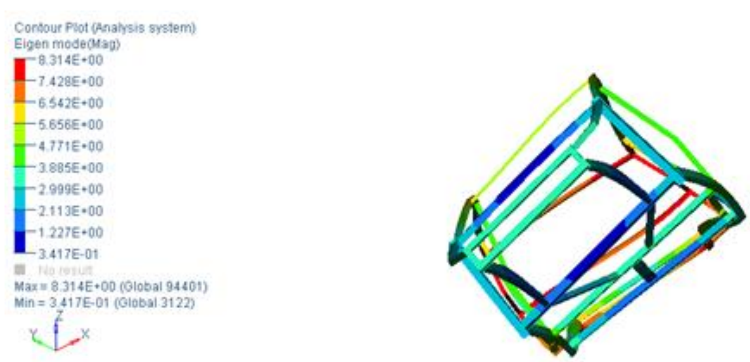

Figure 8 Maximum deformation at mode 9 of the original model

Modification of the original structure

Based on the results presented in the original structure analysis, it could be indicated that the top elements of the structure need to be modified.

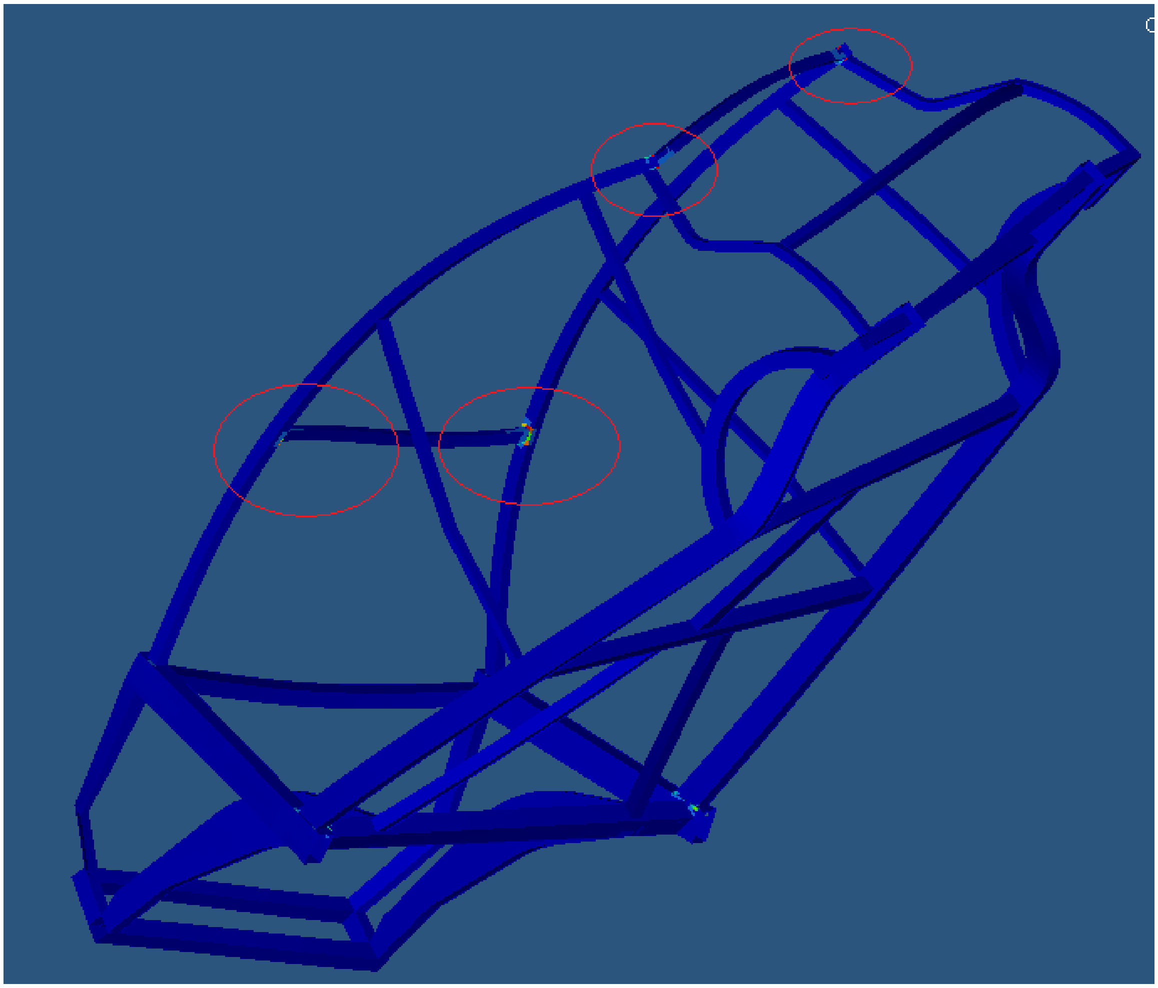

Figure 9 Maximum element strain energy at mode 7 in the original structure

Considering stress stain relationship $\sigma = E\varepsilon$ it is useful to look at the stress in the original structure for further modification:

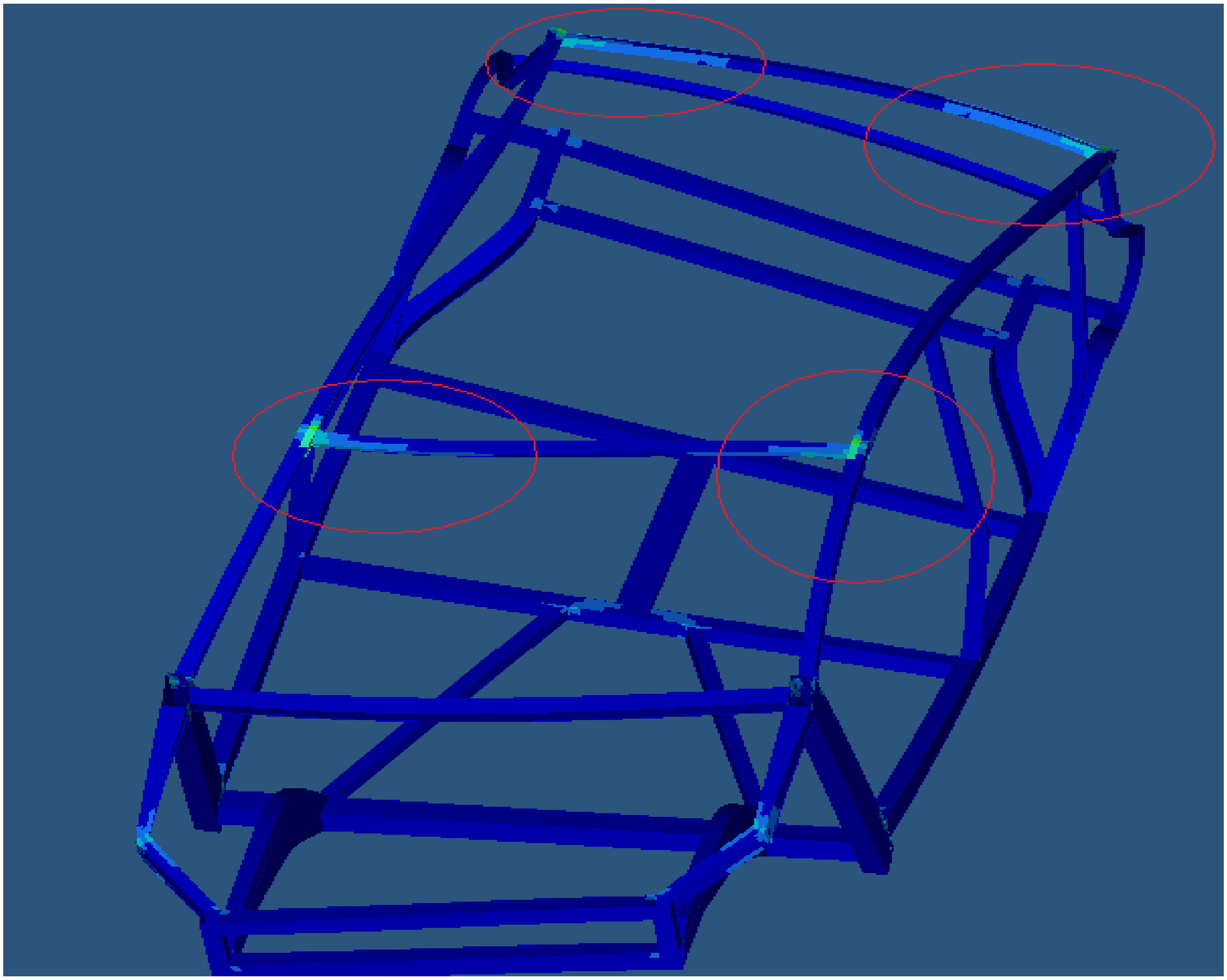

Figure 10 Maximum element stress at mode 7 in the original structure

Now the following components in the original structure are to be updated as following:

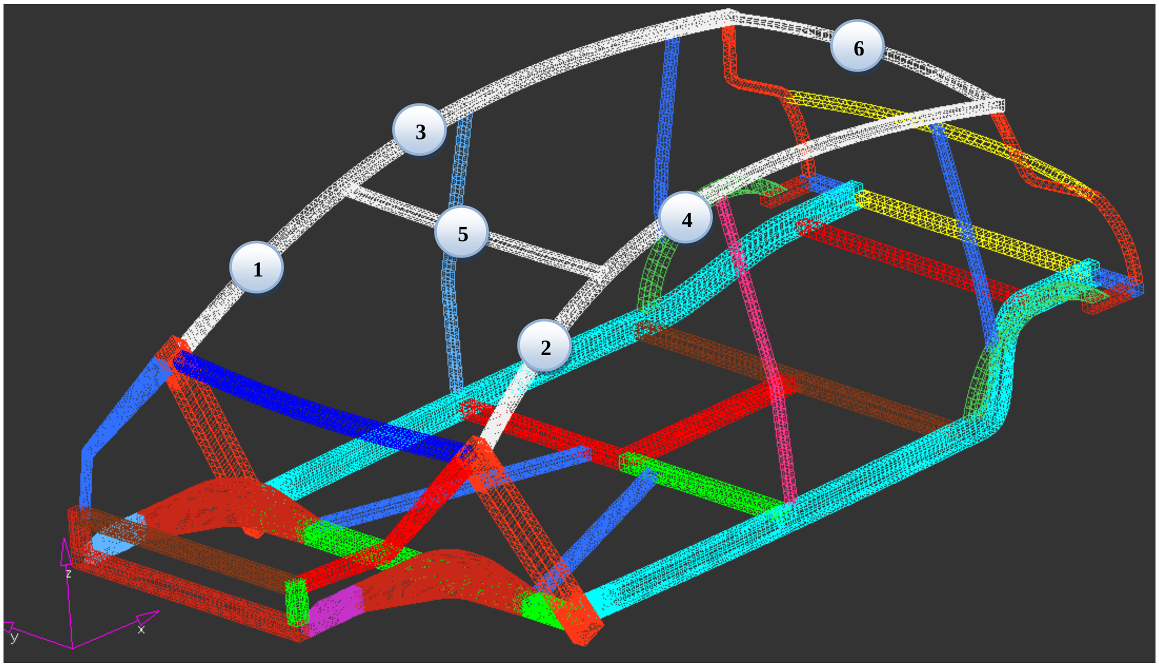

Figure 11 Components shown in white will be updated

Component name	Original thickness (mm)	Modified thickness (mm)
1	3.00	4.00
2	3.00	4.00
3	2.40	3.40
4	2.40	3.40
5	3.20	4.20
6	3.20	4.20

Table 2 Thickness modification table

Results of the Modified Modal

Normal mode frequencies displacement, strain and stress results

Mode: 1
Freq: 0.644E-03 Hz

- Maximum deformation is 6.78.
- Maximum element strain energy density is 0.294E-09.

Mode: 2
Freq: 0.669E-03 Hz

- Maximum deformation is 6.94.
- Maximum element strain energy density is 0.429E-10.

Mode: 3
Freq: 0.815E-03 Hz

- Maximum deformation is 5.31 at grid 155137.
- Maximum element strain energy density is 0.106E-09 in element 69197.

Mode: 4
Freq: 0.888E-03 Hz

- Maximum deformation is 4.25.
- Maximum element strain energy density is 0.466E-10.

Mode: 5
Freq: 0.890E-03 Hz

- Maximum deformation is 7.02.
- Maximum element strain energy density is 0.661E-10.

Mode: 6
Freq: 0.943E-03 Hz

- Maximum deformation is 7.00.
- Maximum element strain energy density is 0.189E-10.

Mode: 7
Freq: 20.3 Hz

- Maximum deformation is 6.61.
- Maximum element strain energy density is 0.330E-01.

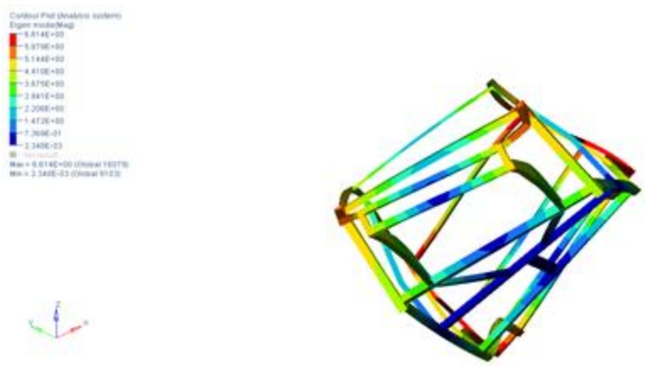

Figure 12 Maximum deformation at mode 7 of the modified model

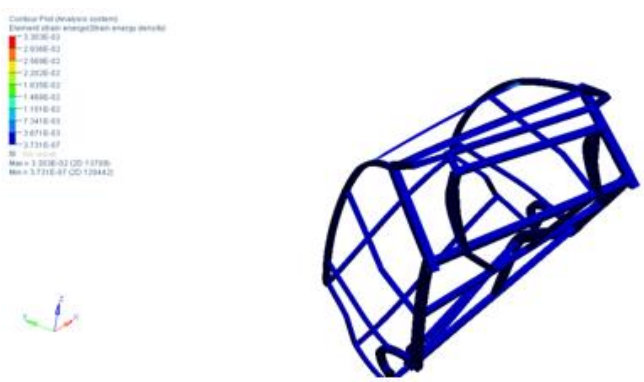

Figure 13 Maximum element strain energy at mode 7 of the modified model

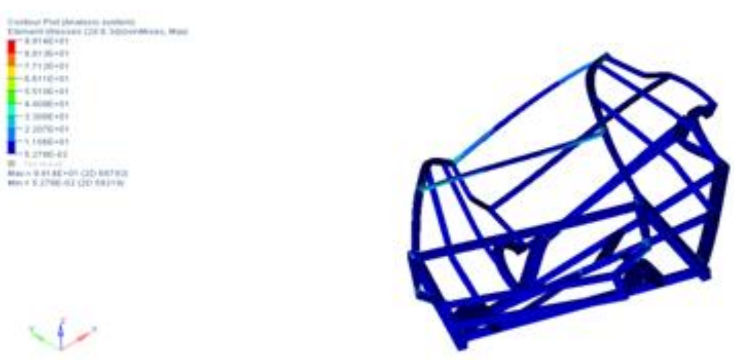

Figure 14 Maximum element stress at mode 7 of the modified model

Mode: 8
Freq: 23.9 Hz

- Maximum deformation is 7.55.
- Maximum element strain energy density is 01.994E-01.

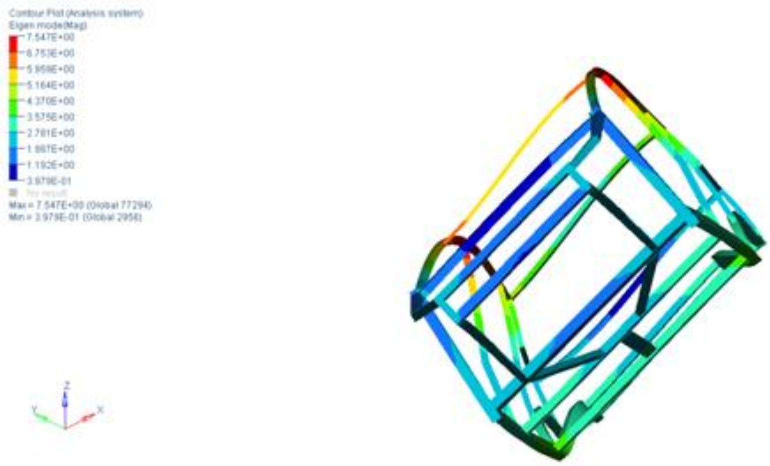

Figure 15 Maximum deformation at mode 9 of the modified model

Mode: 9
Freq: 30.5 Hz

- Maximum deformation is 7.09.
- Maximum element strain energy density is 0.721E-01.

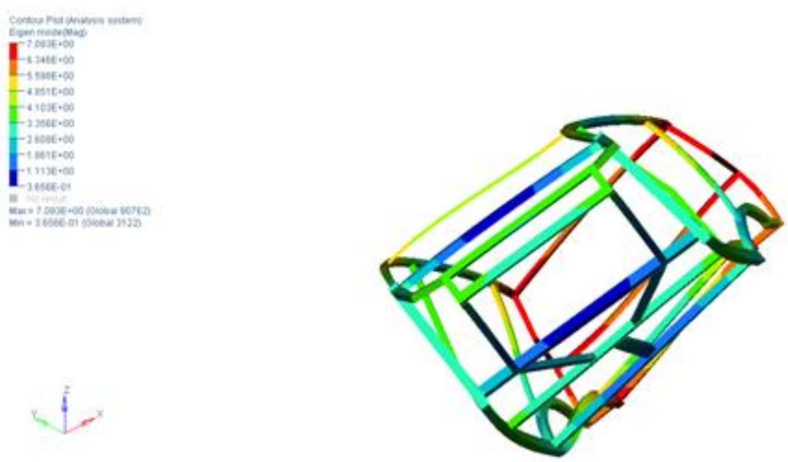

Figure 16 Maximum deformation at mode 9 of the modified model

Model Verification

We can verify the model using the *Free-Free Dynamics with a Stiffness Equilibrium Check* [4]. The Free-Free Dynamics with a Stiffness Equilibrium check verifies that the model will act as a rigid body when it is unconstrained. It also checks the stiffness matrix to verify that it doesn't contain any grounding effects, such as illegally specified in constraints or rigid elements. This check is the standard normal modes analysis in which we will be interested on the first six modes.

When the model has no problems, we will obtain a minimum of six rigid body modes. These modes should have frequencies less than or equal to 1.0E-04 Hz. In our simulations above we have maximum of **0.943E-03 Hz** in our rigid body modes, this since this number is close to the specified value we can consider the simulation to be reasonable.

There are two potential reasons for getting relatively large frequency, first, the mesh could be a little coarse and second we could have large truncation errors.

Discussion and Conclusion

Based on the results presented the objective of the project was accomplished by increasing the frequency at the 7^{th} mode to 20.3 comparing to 17.1. This change will provide an improvement of 3.2 Hz.

Furthermore, the modifications suggested in the study are mainly cost effective, since there are no new components which will added to the vehicle chassis system. Thus no new tooling will be need.

Other then the negative contribution of the added mass to the vehicle frame due to the increase of the thickness in the upper body system; there are no other disadvantages in this modification.

References

[1] Mechanics of Engineering Materials. PP BEnham, Rj Crawford & CG Armstrong; second edition; 1996.
[2] http://en.wikipedia.org
[3] Design of Automotive chassis 2006 Lecture notes. Hong Tae Kang. The University of Michigan-2008
[4] FINITE ELEMENT MODELING CONTINUOUS IMPROVEMENT GUIDE, NASA Goddard Space Flight Center, Greenbelt, Maryland, USA, Mechanical Systems Analysis and Simulation Branch, Code 542

The geometry was taken from a standard part library and modified for this study; also all data are assumptions for proof of concept only.

MS.ME Ahmad A. Abbas

Sr. Analysis Engineer

Ahmad.Abbas@AdvancedCAE.com

www.AdvancedCAE.com