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# A Study of the Acoustic Response of Carbon Fiber Reinforced Plastic Plates

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**Abstract:** This paper gives an introduction to a continuing study detailing the process and development of using both experimental and Finite Element Analysis to characterise the acoustic response of a Carbon Fiber Reinforced Plastic (CFRP) laminate plate provided by a guitar manufacturer. The results show that there is a strong correlation between both the experimental and simulated data which gives the author a strong standing for further work in this area.

**Keywords:** CFRP, Frequency response, Acoustic, Laminate Plate, Experimental, FEM

## 1. Introduction

This paper shall introduce the reader to a continuing project which investigates the acoustic and vibrational properties of carbon fiber reinforced plastic (CFRP) as a sole manufacturing product for acoustic guitars, using both experimental methods and simulated Finite Element Analysis (FEA). While composites have been implemented by a number of guitar companies in the construction process, very few have abandoned the traditional inclusion of wood and, as such, there are currently only three commercial companies known to the author worldwide that solely manufacture acoustic guitars using CFRP.

This research shall endeavour to attain parameters in which the physical and acoustic/vibrational properties match for both simulated Finite Element (FE) models and experimental data which has been collected. The purpose and long term benefit of this will be to ensure that future developments to the instruments carried out by guitar manufacturers can be simulated through FE modelling before prototypes are built. This will ensure that changes to the guitars will be for the acoustic benefit of the instrument and the resources are not wasted preparing guitars that are of a lesser standard than those already in existence.

The research will also provide data which shall enable the author to assess current construction methods and propose modifications which may be used to improve the acoustic quality of carbon fiber guitars thus, in turn, providing a full and quantitative study into the design and material use of modern guitars.

## 2. Use of COMSOL and Model Design

The author shall begin by using the COMSOL Multiphysics© Structural Mechanics module to simulate the natural resonance of the CFRP plate structure provided by a guitar manufacturing company. This analysis is imperative as it shall be used to set the foundation and provide information on the physical characteristics of the specific carbon and lacquer mix used by the manufacturer. The equations used for this model are the default provided by COMSOL.

These results will be compared to those obtained through experimental data collection and, where necessary changes shall be made to the sub domain settings in order to minimise error and provide a high level of confidence for further work.

A 3D model of a rectangular CFRP plate was constructed with dimensions detailed in Table 1 below:

**Table 1** - Model Dimensions

| | |
|---|---|
| **Length [m]** | 0.269 |
| **Width [m]** | 0.23 |
| **Depth [m]** | 0.0033 |

Boundary conditions set [to simulate real life conditions] are so that the top and bottom of the plate are free to vibrate, whilst all edges are fixed in position simulating the clamping system which can be seen in Fig 1. The sub-domain settings for the model can be seen in Table 2 below:

**Table 2** - Sub-Domain Settings

| Variable | Value | Units |
|---|---|---|
| **Young's Modulus** | 1.01e9 | Pa |
| **Density** | 1015 | $Kg/m^3$ |
| **Poisson's Ratio** | 0.28 | |
| **Damping – Loss Factor** | 0.02 | |

For this model, a parametric sweep was carried out covering the frequency range from 0 – 10000[Hz]. To achieve this frequency range 4 identical models have been created and each sweep has been over 2.5[kHz] i.e. 0-2500, 2500-5000 etc. The parametric sweep was carried out in steps of 10[Hz] and a downward acting force of 5N was applied at a point in the centre of the plate.

Experimental data was collected by tapping the centre of a CFRP plate with a nylon tipped drumstick. The output was recorded into the software package Logic 9 using an Earthworks M30 high definition measurement microphone. The waveforms were then analysed using fuzzmeasure Pro 3[1].

**Figure 1 –** Clamping System

## 3. Results and Discussion

Figure 2 shows the results of the experimental data collection. This graph is a comparison of five separate recorded 'hits' of the CFRP plate and the frequency response output through fuzzmeasure. Figure 3 shows the simulated frequency response of the CFRP plate through COMSOL, namely the root-mean-square displacement integrated over the top surface of the plate. Finally, figures 4 & 5 show the microphone positions used for the experimental data collection.

It can be seen from Figures 2 & 3 that there is a strong correlation between the experimental and simulated data. In both cases the fundamental is located at 93 Hz and on closer examination there are a further 22 points of commonality.

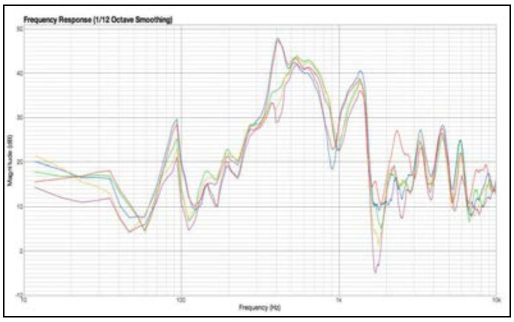

**Figure 2 –** Experimental Data Frequency Response of CFRP

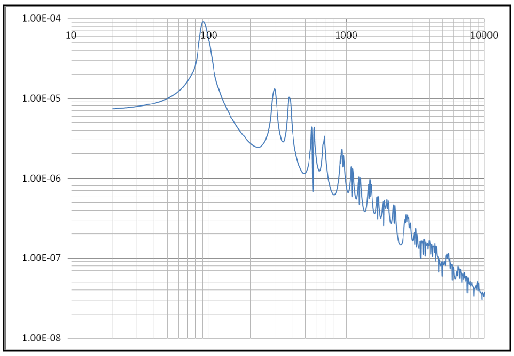


**Figure 3 –** Simulated Data Frequency Response of CFRP

**Figure 4 –** Microphone Position, over CFRP

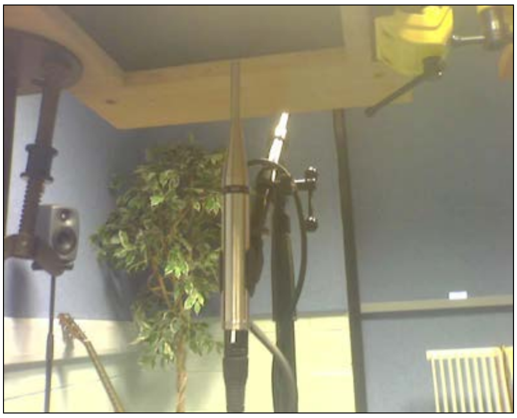

**Figure 5 –** Microphone Position, under CFRP

Table 3 below details the common frequencies found in both the experimental data and simulated data which, for this initial study proves to be great results.

**Table 3 -** Comparison of matching experimental and simulated frequency response

| **Frequency [Hz] (experimental data)** | **Frequency [Hz] (simulated data)** |
|---|---|
| 93 | 93 |
| 181 | 172 |
| 199 | 208 |
| 275 | 280 |
| 380 | 384 |
| 410 | 401 |
| 451 | 453 |
| 544 | 568 |
| 638 | 619 |
| 1353 | 1335 |
| 1705 | 1700 |
| 1851 | 1852 |
| 2220 | 2211 |
| 2736 | 2738 |
| 4564 | 4544 |
| 5900 | 5934 |
| 7441 | 7435 |
| 7505 | 7518 |
| 8085 | 8022 |
| 8636 | 8631 |
| 8853 | 8841 |
| 8929 | 8931 |
| 9076 | 9071 |

In Order to ensure minimal data was lost due to the mesh size or the selection of a specific point on the model the root-mean-square displacement integrated over the top surface of the plate was taken into account. This was carried out by introducing a boundary integration coupling variable named 'mydisp' on the top surface of the plate only.

The expression which followed was:

**'sqrt((real(disp_smsld)*real(disp_smsld)) + (image(disp_smsld)*image(disp_smsld)))'**

Thus ensuring harmonics were not lost due to a random point selection on the model.

The method used for post processing followed the following steps:
Post-processing > Domain plot parameters
Point plot > select point 5 > type 'mydisp' in the expression field > apply.

From the graph which follows select the ASCII button at the top and save the data (.txt) file.

This process was carried out for each individual model and the data files were then consolidated within Microsoft EXCEL giving a graph which covered the simulated frequency range.

## 4. Conclusions

This initial examination of the project has shown there is a strong correlation between both the simulated and experimental data. There are however, small discrepancies which, through further study and analysis, will be smoothed over to provide a more accurate model. Areas which will be included in further study are the damping effect and if it is possible to replicate with a limited margin of error, the specific acoustic characteristics of the resin/carbon mix used by the guitar manufacturer.

The results have shown that there is a consistent match and agreement through both the simulated and empirical data collected providing the author with a high level of confidence for further work in this area.

## 5. Acknowledgements

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## 6. References


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