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Experimental Testing of Door Panel Boundary Conditions to Determine NVH Variability.

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Abstract

The variability of measured frequency response functions (FRFs) from nominally identical structures is a well-known phenomenon and trying to eradicate it increases the design challenge for automotive manufacturers. In this paper a vehicle door is experimentally tested in order to assess the effect of variability in the attachment boundary conditions between the door structure and trim components upon measured FRF data. Plastic clips can be used to hold the trim to the door panel, so individual clips were systematically removed and then replaced in order to generate a set of measured FRFs that demonstrate how individual property changes can influence the global structure. Point and transfer FRFs, with corresponding normalised standard deviations, were measured by exciting the door panel and measuring the response both on the door panel and on the attached trim. The door response was found to vary by up to 10% over all clip combinations, and this is compared to the test variability. A newly developed function that predicts the FRF variability due to measurement test error was also applied. The results of this prediction match closely with the normalised standard deviation calculated from repeat FRF measurements taken on the structure. This will therefore enable test-to-test variability to be separated from structure-to-structure variability.

1. Introduction

In an ever competitive market for the top of the range automotive vehicles, the sound and vibration levels are becoming increasingly significant as a means for customers to distinguish quality between vehicles. Simulation packages, as a method of improving such areas in the automotive industry are an invaluable tool, however the reality often lies far from what is predicted ^[1,2] as a result of variation in manufacturing processes, material tolerances and testing procedures to name a few. Although the customer will not easily be able to compare a range of vehicles to determine whether their car produces more or less noise on average, by reducing the variability in the product, measured behaviours such as vibration responses will match those predicted by the models much more closely.

Large variability can often be found at material boundaries ^[3], where discrepancies appear from joining methods. As part of an investigation into the variability sources in automotive vehicles that seeks to both quantify and improve any uncertainties, the boundary conditions are an area of interest. This paper will look to quantify the boundary conditions between a vehicle door and its trim. The system to be tested uses clips that are held in tightly at one side, but slid into place on the trim side, leaving room for potential manoeuvrability, and therefore variability. An experiment will be conducted that observes the vibration transfer path as the boundary conditions between the door and the trim vary.

The standard deviation will be used to analyse the results and show the spread from the mean is determined by:

$$s(f) = \left(\frac{1}{n-1} \sum_{i=1}^n (FRF(f)_i - \overline{FRF}(f))^2 \right)^{\frac{1}{2}} \quad (1)$$

where s is the standard deviation, f is the frequency, n is the number of measurements, FRF_i is the data, which in this case is the noise/vibration transfer function of the i^{th} set of data, and $\overline{FRF}(f)$ is the mean of the FRF at a specific frequency obtained by:

$$\overline{FRF}(f) = \frac{1}{n} \sum_{i=1}^n FRF_i(f) \quad (2)$$

It is also convenient to define the standard deviation in terms of a fraction of the measured data, which is also known as the normalised standard deviation, or the coefficient of variation.

$$\hat{s}(f) = \frac{s(f)}{\overline{FRF}(f)} \quad (3)$$

This will produce a non-dimensional number; for example $\hat{s}(f) = 0.1$, then the data would have a scatter of 10% of the point that is has been averaged about.

A function developed by Bendat ^[4] in 1978 provides a method of calculating the normalised standard deviation without the use of the frequency response functions directly. Instead, the only inputs into the equation are the coherence, γ and the number of data sets, n_d see equation 4:

$$\varepsilon[|FRF|] = \frac{\sqrt{\text{var}(|FRF|)}}{|FRF|} \approx \frac{(1 - \gamma^2)^{1/2}}{|\gamma| \sqrt{2n_d}} \quad (4)$$

where \hat{H}_{xy} is the frequency response function and $\varepsilon[|\hat{H}_{xy}|]$ is the normalised standard deviation, or the expected random error. A full derivation can be found in Bendat's 1978 paper ^[5].

2. Experimental Procedure

A single JLR XJ front passenger door is tested by suspending it from an A frame in order to get as close to free-free conditions as possible. Both a shaker and an impact hammer are tested to determine the most appropriate source of excitation. The set up for the shaker can be seen in Figures 2.1-2.2 whereby the stinger was attached by means of a glued screw. Large efforts were taken to ensure that the stinger was aligned at right angles to the excited surface to ensure maximum energy enters the test subject. The use of a tripod with fixed dimensions ensured that the height and angle remained the same for each clip combination.

A force transducer was used at the point of excitation, which alongside accelerometers placed at various locations as shown in Figure 2.1, was able to produce data to determine the frequency response functions (FRF). The three accelerometers were placed firstly at the force transducer point to produce point mobility results, the two remaining were placed on the outer door and inner panel. The positioning of the accelerometers was not changed throughout the testing.

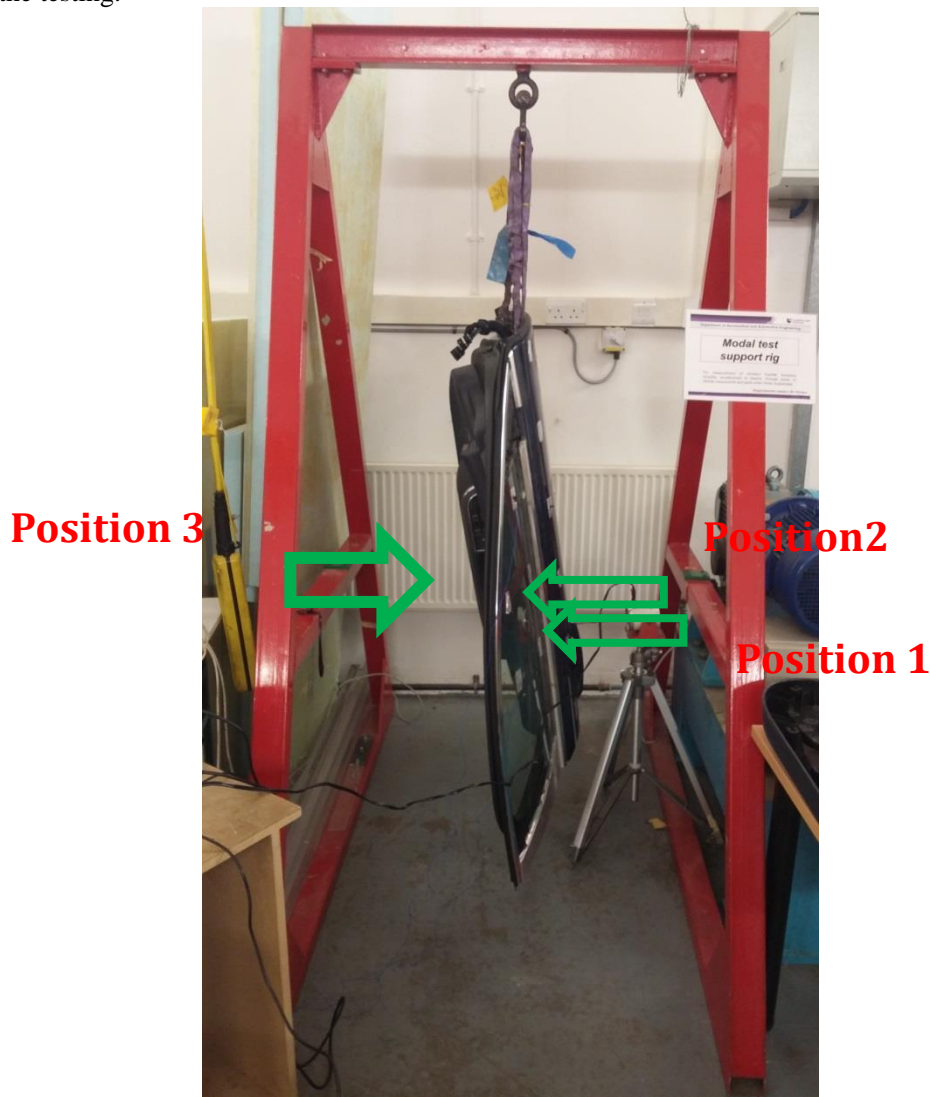


Figure 2.1: The door set up suspended from an A frame. A shaker was used as the vibration source and is connected to the door panel by a glued bolt. The accelerometer positioning is denoted by the green arrows.



Figure 2.2: Connection method using the stinger and screw. The screw has been fixed onto the vehicle surface using superglue.

Testing was taken using both an impact hammer and the shaker set up to determine the most appropriate method. No other variables were taken, and 10 repeat readings for each excitation source were recorded.

To investigate the extent of the variability due to different clip combinations, the door was tested with individually removed clips which were replaced and the door was then tested again after the next clip had been removed. At any one time, only one clip would be vacant and repeat results for each clip were also recorded for up to 10 times to observe the measurement variability in comparison to the variability due to the clip permutations.

Prior to testing the clip permutations, measurements were undertaken to determine how disassembling and reassembling the door would contribute to the overall variability. The inner panel of the vehicle door was held to the outer panel by four screws, each of which creates a potential variability when tightening the screws. Further variability could be sourced through wear and tear in the threads and other areas as the door is removed and replaced repeatedly. The testing consisted of taking repeated measurements after removing and replacing the inner door panel several times.



Figure 2.3: An example of the clips in place with one removed.

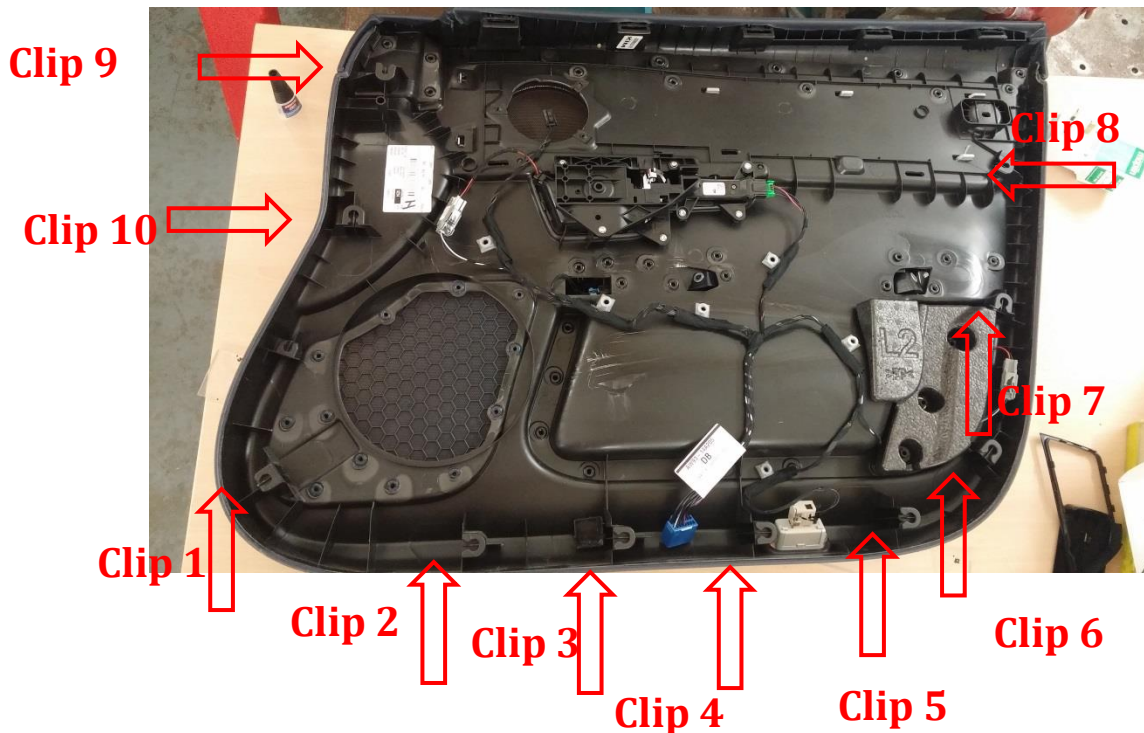


Figure 2.4: The positioning of the clips and their labels are given and one clip is removed at a time, the door is reassembled, then the clip is replaced once the measurements have been taken.

3. Results and Discussion

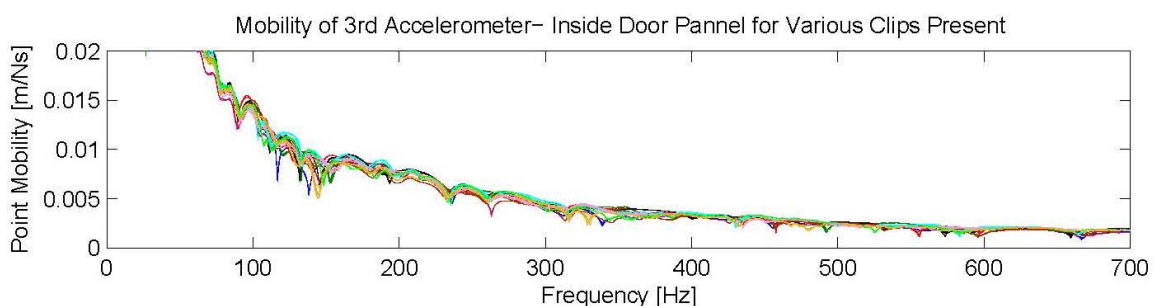


Figure 3.1: Showing the mobility for all 11 combinations of the clips. The graphs show the ratios between the excitation points and the response point on the inner door in order to see the transfer path of the vibrations through the whole door.

The results as shown in Fig. 3.1 are of the point mobility for the permutations of all 11 clips which have been measured over the transfer path travelling from the force transducer (at the excitation point) to position 3 in Fig. 2.1. The normalised standard deviation, seen in Fig. 3.2 over a frequency range of 100-600Hz was found to be on average approximately 0.1. The variability was therefore on average around 10% when all clips were tested. By removing a clip entirely, the remaining area is left to vibrate freely. This may in some cases be a worst case scenario, however this may not be the case when compared to a clip that produces severe rattle which may be why that variability is not as great as one might expect. The removal of a clip will cause more movement in the door panels however vibrations that would have previously been transmitted now have fewer paths with which to be transmitted.

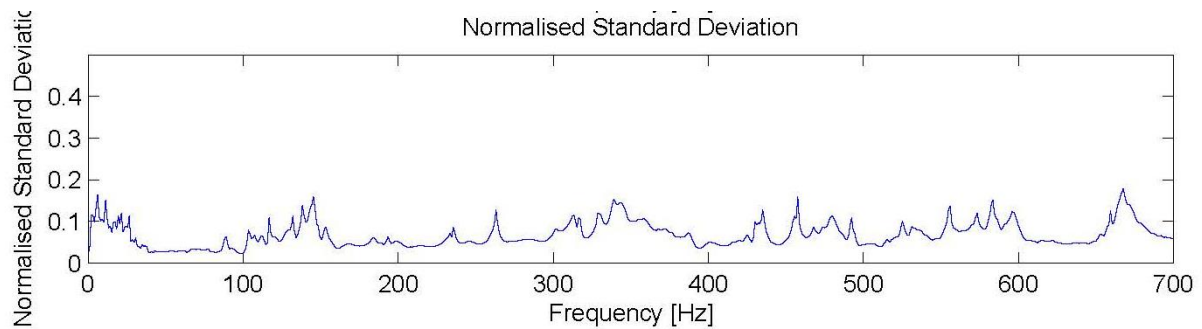


Figure 3.2: The normalised standard deviation of the mobility for all permutations of the clips.

It is important to be able to determine how much of the variability was due to only the variation of the clips rather than any that may be contributed as a result of variations in removing and replacing of the door panel for example. After conducting a set of measurements where only the inner trim was moved as seen in Fig. 3.3, the averaged normalised standard deviation, taken over a 100-600Hz range was found to be 0.05. When compared to testing in which nothing is changed, an increase of up to ten times the variability is noticed.

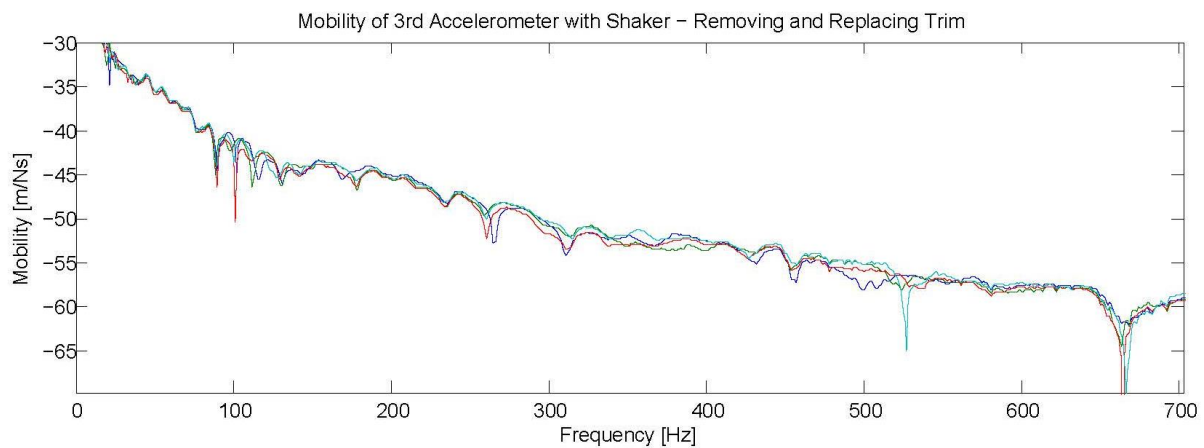


Figure 3.3: The mobility calculated for measurements taken after the inner door panel has been removed and replaced a number of times. The normalised standard deviation was found to be 0.05 after averaging over the 100-600 Hz frequency range.

3.1 Coherence:

Using the coherence data is often a useful tool in determining the quality of a measurement as it examines the linearity a set of data. The normalised standard deviation is related to the coherence through Eqn.1, which when applied to the coherence data will give an estimate of the variability attributed to the measurement taking process. When compared with the directly recorded measurement variability, close comparisons can be observed between the two. Some sharp peaks in the measured normalised standard deviation when compared with that of the predicted data can be noticed. The peak appear to be present in the predicted data, however these are not as prominent. It can also be noticed that the measurement variability (red) generally has slightly higher values than that of the predicted data.

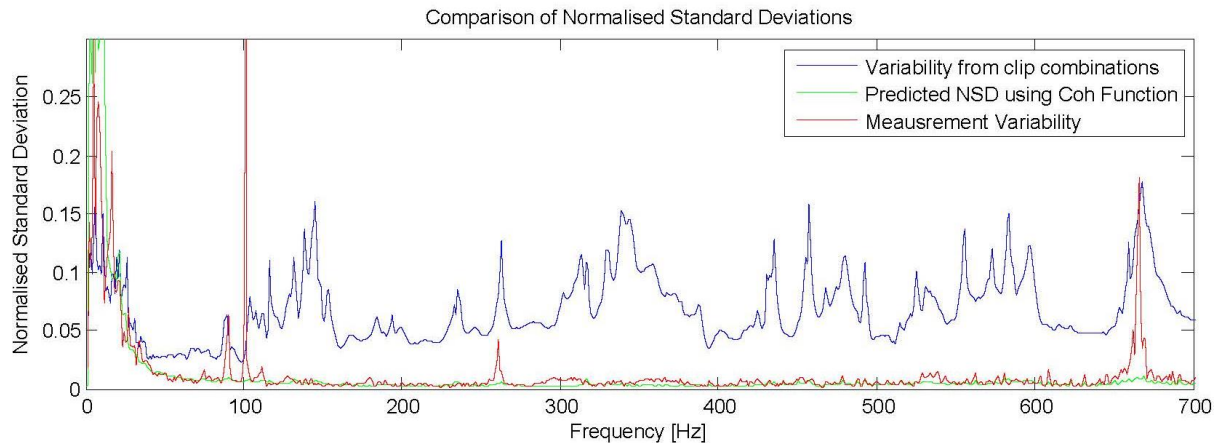


Figure 3.4: The normalised standard deviation for the combinations of each clip (blue), the predicted variability attributed to the measurements (green) and the measurement variability directly measured for comparison (red).

The function that has been applied does not include the uncertainty that results from the bias error, which although would not account for the spikes, would bring the average slightly up to match the directly measured data more closely. The spikes in the directly measured data are a result of a sharp drop in the amplitude. Due to noise, the ratio between the average and the change between measurements leads to a large normalised standard deviation.

Conclusions

A series of frequency response function measurements have been run on a JLR XJ door in order to quantify the vibrational variability caused by the changing boundary conditions between the door and its trim. The trim was held to the door by 11 clips, and by removing an individual clip each time, different permutations of the clips were investigated.

A variability of 10% was found by calculating the normalised standard deviation from the mobility. Further testing showed that the variability contributed as a result of removing and replacing the trim panel was as much as 5%, a significant increase from <1% when nothing was changed. This is attributed to the likelihood of the different torques that the screws would likely be put under each time the panel was reassembled.

Comparisons of the measurement variability were taken and compared with predicted values that were calculated using the coherence data from the main clip variability testing procedure. The predicted and directly measured variability results were shown to have only minor deviations between one another which would largely be resolved with the inclusion of the bias error when calculating the predicted data.

Acknowledgements

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