

Automotive Modal Testing Support and CAE Correlation Using Altair HyperWorks

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Abstract

Part 1 – Modal Testing Support

To derive the natural frequencies and mode shapes of a given structure, the test Engineer has to decide on excitation positions that will efficiently excite all the modes of the structure in the frequency range of interest. Excitation positions are usually decided upon from experience or trial and error methods which can be time consuming and still not capture all of the modes in the selected frequency range. Using Altair HyperStudy and Radioss (bulk), Pre-test CAE analysis has been carried out to identify effective excitation positions before the commencement of modal testing, thereby significantly reducing pre-test lab time.

Part 2 – CAE / Modal Test Correlation

Improving the accuracy of CAE normal modes predictions can be an extremely laborious task. Using Altair OptiStruct, improved correlation to test results for multiple modes has been carried in one optimisation analysis considering multiply variables. OptiStruct optimisation to define variable settings that can be used for future CAE normal modes predictions.

Keywords: Modal Testing, Optimisation, OptiStruct, HyperWorks, HyperStudy

1.0 Introduction

The paper is split into two parts. The first part describes a process of using Altair HyperWorks to support pre-modal testing.

At the beginning of a modal test, the test Engineer has to decide where to locate shakers and/or impact hammer strike positions that will efficiently excite the structure in the frequency range of interest. More than one location is often selected and is usually based on the experience of testing similar structures or from trial and error pre-testing. In the latter case, significant testing time can be consumed exciting the structure at trial locations and interrogating results to ascertain their suitability. Selection from experience or trial and error may result in inefficient excitation points being selected, potentially leading to modes being missed.

To identify efficient excitation positions, Altair HyperWorks can be used to carry out pre-test analysis. The process assumes that suitable CAE models exist for the structure to be tested. In automotive applications this is often the case. The process is fundamentally similar to the trial and error approach used in testing, but by employing HyperStudy, several CAE simulations can be automatically written and executed, each with a different excitation position, and the results brought back into the HyperStudy environment. Assessment of the most efficient excitation positions can then be made based on the CAE trials. This process is described in more detail in the following sections.

The second part of the paper describes a process of improving the accuracy of CAE modal predictions. CAE modal prediction comparisons are often made to modal test results. In cases where improvements in CAE prediction accuracy is required, manual modification of selected model parameters is typically carried out until improved correlation is achieved. In this approach, model parameters are usually changed individually and assessment is made of the effect on modal results. Individual changes to parameters do not take into account interactions between parameters and therefore combinations of individually changes do not always give the anticipated cumulative effect.

In addition to interaction between selected model parameters, the situation is made even more complex by individual changes usually only having an effect on certain modes. Each mode shape involves local flexing of the structure. The changed model parameter then may or may not have an effect on the localised flexing and therefore may only have an effect on certain modes.

Considering these complexities, arriving at improvements in CAE predictions for multiple modes using a manual process can involve large numbers of iterations and consume many man hours. An alternative to this approach is to use Altair's optimisation technology to find the optimum combination of selected model parameters to minimise the difference between CAE predictions and test results. This process is described in more detail in the following sections.

2.0 Part 1 – Modal Testing Support

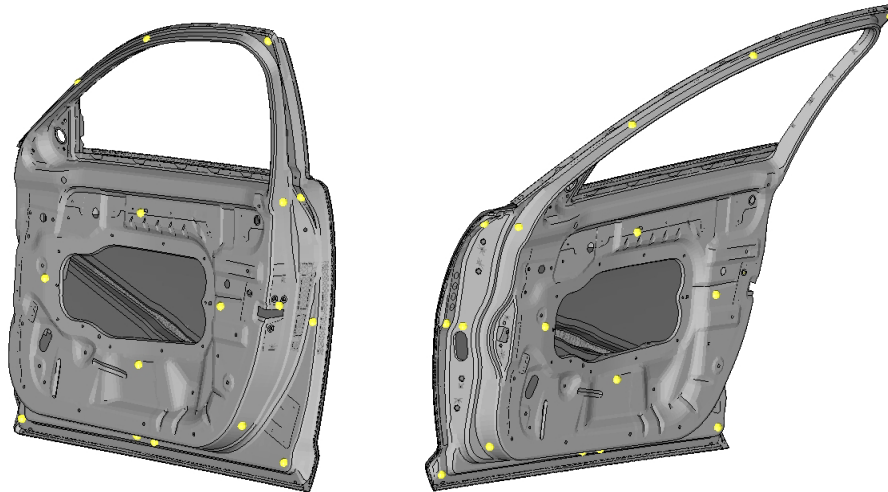
The process is divided into six steps as follows:

1. Identify a long list candidate excitation points by “Engineering Judgement”
2. Normal Modes CAE Analysis
3. Frequency Response CAE Analysis
4. Select variables and responses using HyperStudy
5. Create and execute a Design of Experiments using HyperStudy
6. Analyse results

2.1 Step 1: Identification of Candidate Positions

As a first step, the structure is examined and potential excitation positions are identified. Theoretically there is no limit to the number of positions that can be selected. The practical limitation comes from the number of CAE analysis runs that can be realistically carried out which is in turn is linked to model size, CPU memory usage, available disk space and model run times.

An example of selected candidate positions is shown in **Figure 1** for an automotive Body in White (BIW) front door. In this example, modes of the upper frame and inner panel were of interest. To excite these modes, 21 candidate positions were selected and at each position, excitation could be applied in X, Y, and Z directions, giving a total of 63 potential excitations.



● Candidate Excitation Positions

Figure 1: Candidate Excitation Positions for Upper Frame and Inner Panel Modes

2.2 Step 2: CAE Normal Modes Analysis

The second part of the process requires that a CAE normal modes analysis is carrying out over the frequency range of interest. The purpose of the normal modes analysis is to:

- To identify number of modes.
- To identify the frequency of each mode.
- To identify the peak eigenvector displacement for each mode.

For the door example, 28 modes were found in the frequency range of interest. This included modes of the upper frame and inner panel, which was the main focus of the work, and also modes involving the remaining parts of the door structure.

Figure 2 shows an eigenvector contour plot of one of the door upper frame modes. The position and dominant direction of the maximum displacement is also shown in the Figure. This information is recorded for all modes to be used in a later stage of the process.

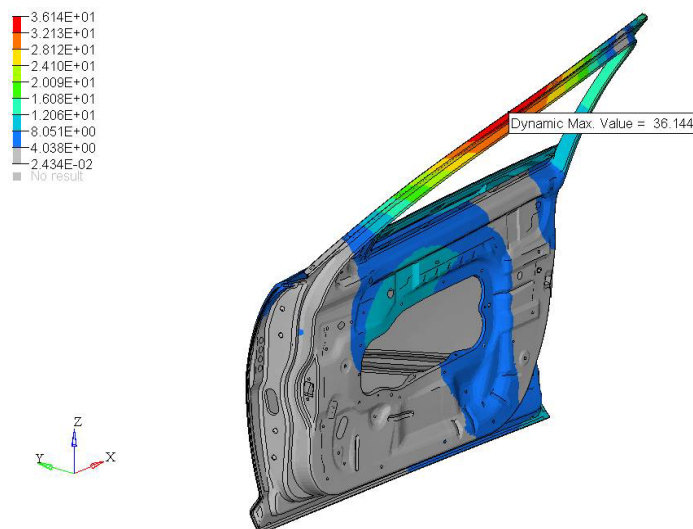


Figure 2: Eigenvector Contour of Plot of an Example Mode Showing the Position of Maximum Displacement

2.3 Step 3: CAE Frequency Response Analysis Setup

The next step is to setup a frequency response analysis to excite the structure at the candidate positions. The setup is required so that HyperStudy can be used in later stages to switch excitations on and off. The process of achieving this, is to setup frequency response excitation through spring elements attached to each of the candidate positions. A small mass element is also added to the excitation end of the spring to ensure numerical stability. By defining the spring stiffness as variables in HyperStudy, the excitation can be switch on by defining a high spring stiffness, or switched off by defining a zero spring stiffness, thereby disconnecting the excitation from the structure. **Figure 3** shows and illustration of the frequency response setup for one candidate position, with X, Y, Z excitation.

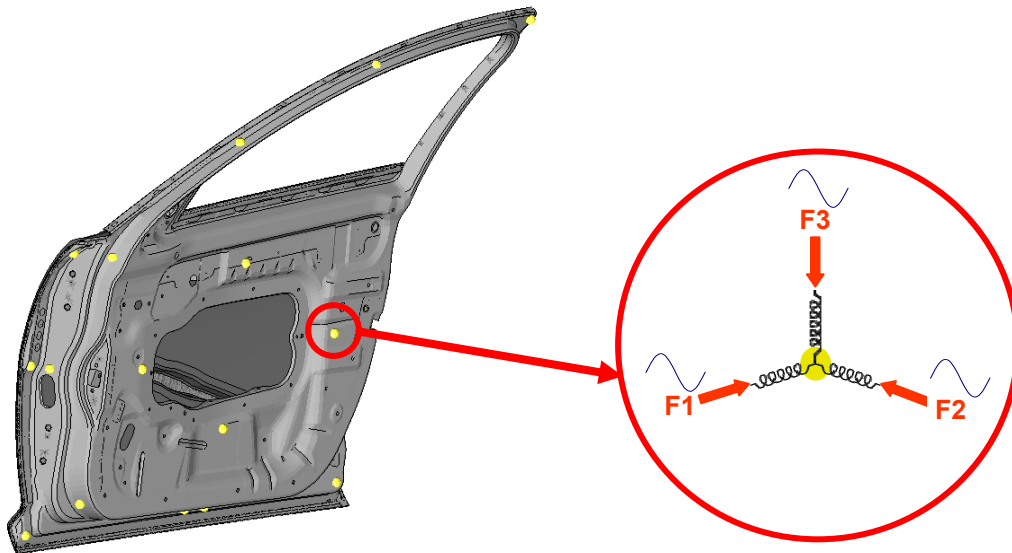


Figure 3: Frequency Response Setup, Excitation Through Spring Elements

Results output for the frequency response analysis was defined as velocity output for each of the nodes that were defined to be points of maximum eigenvector displacement. The number of nodes will be equal to the number of modes provided that points of maximum displacement are not common for more than one mode. The output frequency resolution and damping should be defined to ensure that peak responses at the modal frequencies are adequately captured. As only a small number of nodal responses are selected for output, the results file size will be relatively small thereby reducing disk space demands.

2.4 Step 4: HyperStudy Variables and Responses Setup

Once the frequency response analysis is setup, it is read into HyperMesh. By launching HyperStudy from HyperMesh, spring stiffness, at the response locations, are automatically recognised as potential variables. This allows them to be easily selected and assigned a lower (zero) and upper stiffness value.

From a nominal frequency response run, velocity results at the maximum eigenvector position, at the respective modal frequency were defined. In the door example 28 modes were identified and therefore 28 responses were defined. Response definition was carried out directly in HyperStudy by selected the frequency response output file with reference to the required result within it. The HyperStudy variable and response definition process is illustrated in **Figure 4**.

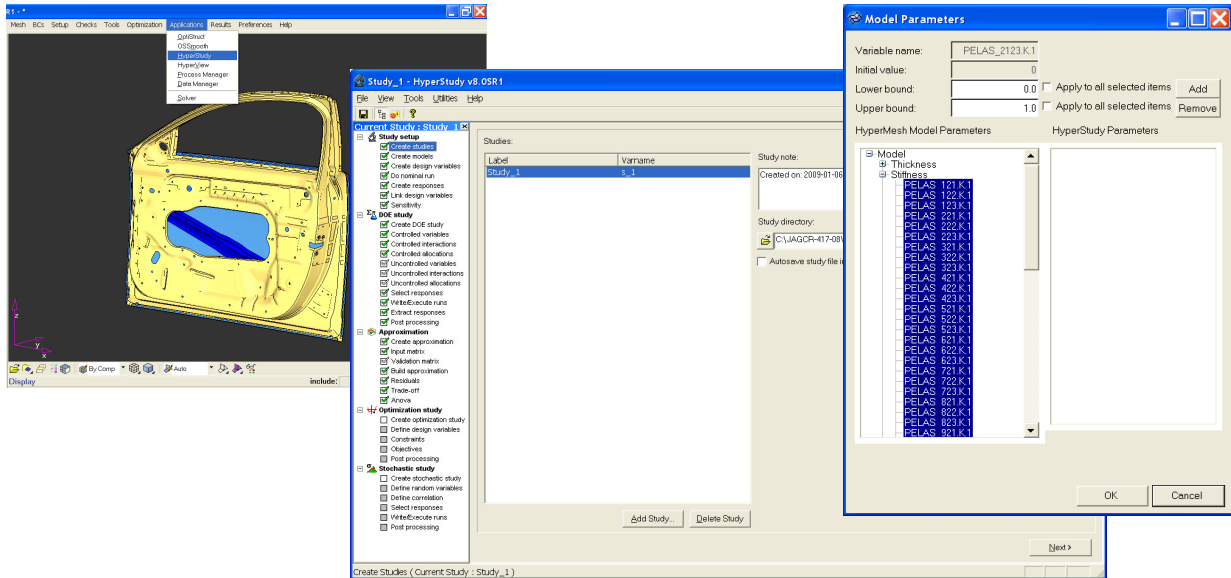


Figure 4: HyperStudy, Variable and Response Setup

2.5 Step 5: HyperStudy Design of Experiments Setup

Having defined variables and responses, a design of experiment (DOE) study is setup. The DOE run matrix is relatively simple in that only one variable is set to the upper value in each run. This effectively turns on one excitation point in turn resulting in a diagonal matrix as illustrated by a section of the matrix shown in **Figure 5**. Using the DOE run matrix, HyperStudy automatically creates input decks with the specified variable settings for each run. The analysis runs can also be automatically submitted by HyperStudy or submitted externally via a user defined script.

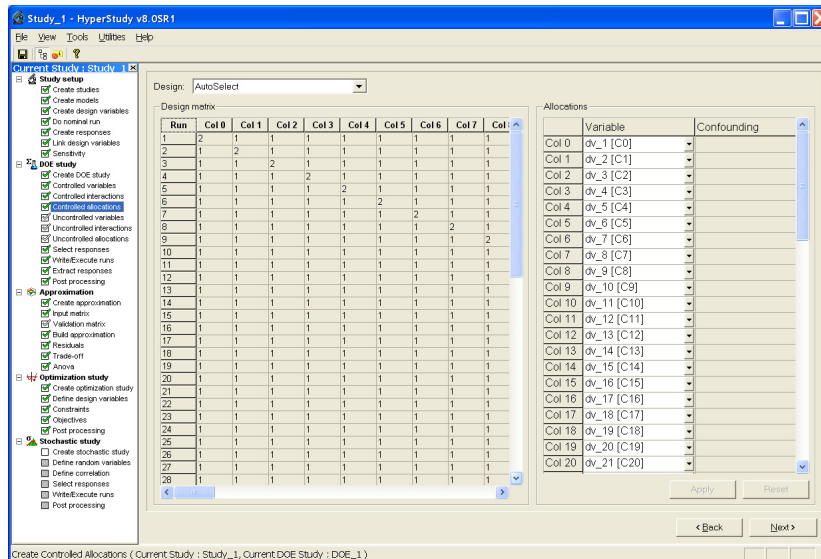


Figure 5: HyperStudy, DOE Run Matrix Setup

2.6 Step 6: HyperStudy Results Analysis

For the door example, 63 analysis runs were written and executed by HyperStudy. The results of the analysis runs were automatically extracted and post processed using HyperStudy visualisation tools. An example of the post processed results is shown in **Figure 6**. It can be seen from this Figure that several excitation positions do not produce

high levels of response and are therefore ineffective excitation locations. By interrogating the results, some judgement is required to select appropriate excitation locations that give as many high responses as possible, across the range of modes. In the door example, two excitation positions were selected that excited modes of the upper frame and inner panel. These locations are shown in **Figure 7**.

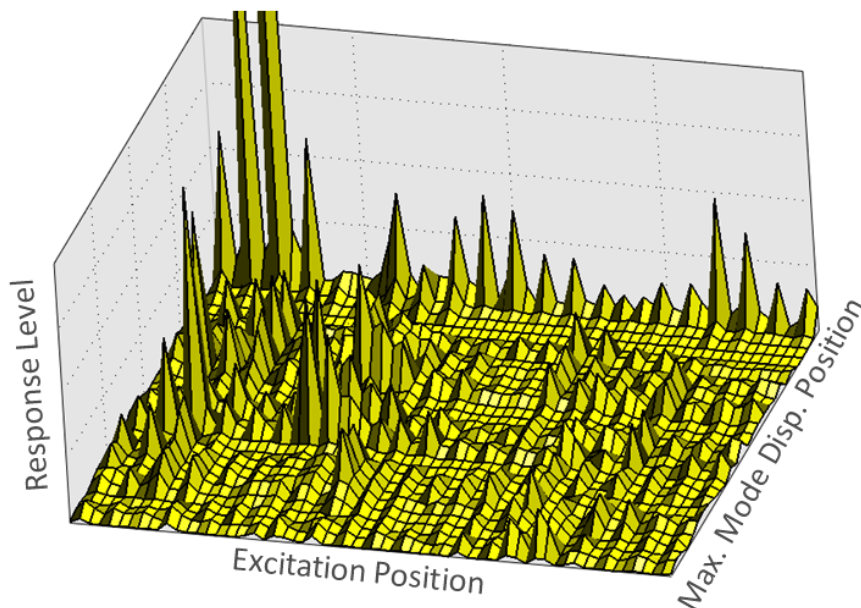


Figure 6: HyperStudy, DOE Results Used to Select Efficient Excitation Positions

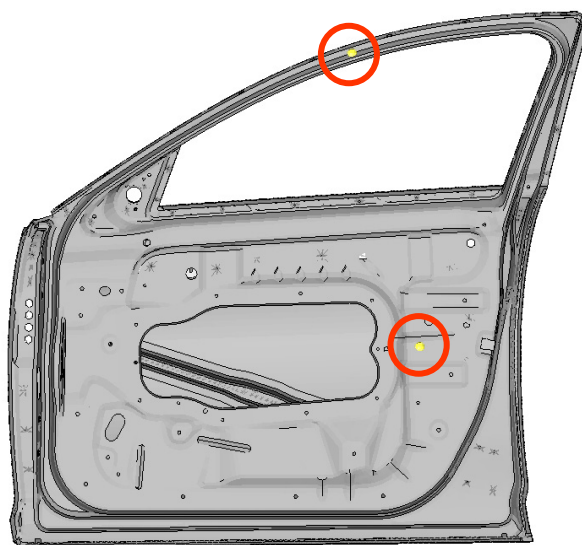


Figure 7: Efficient Upper Frame and Inner Panel Excitation Positions Selected from HyperStudy Results

3.0 Part 2 – CAE / Modal Testing Correlation

3.1 Comparison of CAE predictions to Modal Test Results

CAE modal prediction comparisons are often made to modal test results. **Figure 8** shows the results of a CAE prediction of front door modal frequencies compared to test data results as a percentage difference. The results are shown for the first 10 flexible modes of the door structure.

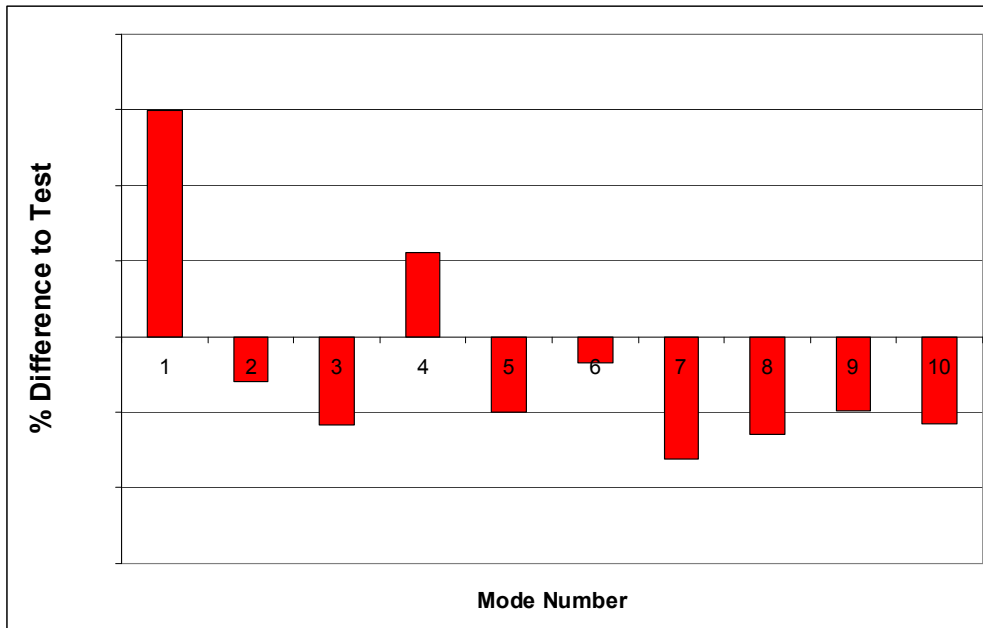


Figure 8: CAE Model Frequency Predictions as a % Difference to Test Results for the First 10 Modes.

In order to improve the prediction accuracy of CAE results, a five step optimisation process is suggested as follows:

1. Set the objective
2. Select variables (things that could be wrong in the model)
3. Set variable ranges
4. Run the optimisation
5. Post Processing

3.2 Step 1: Optimisation Objective Setup

The optimisation objective is setup to minimise the difference between test and CAE natural frequencies by modifying the value of selected variables. To avoid achieving correlation for only a few modes, the objective is a function, based on multiple modes. Modifying variables to achieve good correlation for one or two modes may result in good correlation for the wrong reasons. However, modification of variables to achieve good correlation for multiple modes results in a more general solution and therefore more reliable variable settings.

For the door example the first 10 modes were selected. The OptiStruct objective was setup to minimise the sum of squared difference of test and CAE natural frequency results. An illustration of the objective function equation is shown below:

$$\text{Minimise: } ((M1-T1)^2)+((M2-T2)^2)+((M3-T3)^2)+((M4-T4)^2)+((M5-T5)^2)+((M6-T6)^2)+((M7-T7)^2)+((M8-T8)^2)+((M9-T9)^2)+((M10-T10)^2)$$

Where **Mn is Model Results**
 Tn is Test Results

(numbers indicate mode number)

3.3 Step 2: Optimisation Variables Selection

In order to improve CAE results, model parameters that are suspected of affecting the prediction accuracy have to be selected. Likely candidates for selection are areas of model uncertainty such as material properties, or areas of variability such as manufacturing tolerances. Using the door model as an example, potential model parameters were selected as listed below:

- Structural Adhesive Young's Modulus
- Structural Adhesive Material Density
- Gap Filler Young's Modulus
- Gap Filler Material Density
- Panel Thickness
- Panel Mass
- Damping Pad Young's Modulus
- Damping Pad Material Density
- Spot Weld Young's Modulus

Manual modification of combinations of these parameters would require many iterations and several man hours in order to achieve an improved level of correlation across a number of modes. As an alternative approach, Altair OptiStruct can be used to find optimum settings for these parameters.

3.4 Step 3: Optimisation Variable Ranges

From the list of variables selected, information may exist to suggest the likely range of values that the variables can adopt. In these cases, the variable range should be included as part of the optimisation setup. This ensures that during the optimisation analysis, the solver will only search in the feasible range.

In some cases, a high level of uncertainty may exist as to variable range. In this instance, a wide variable range should be specified. As explained in the previous section, by including multiple modes as part of the optimisation objective setup, there is a higher probability that reliable variable settings will be derived. By specifying a wide range for variables with a high level of uncertainty, the optimisation is then not restricted in assigning an optimised value.

3.5 Step 4: Optimisation Analysis

Figure 9 shows the Optimisation history of the objective function. It can be seen that the optimisation analysis converged after 21 iterations and the objective function reduced quite substantially to a value close to zero by the final iteration.

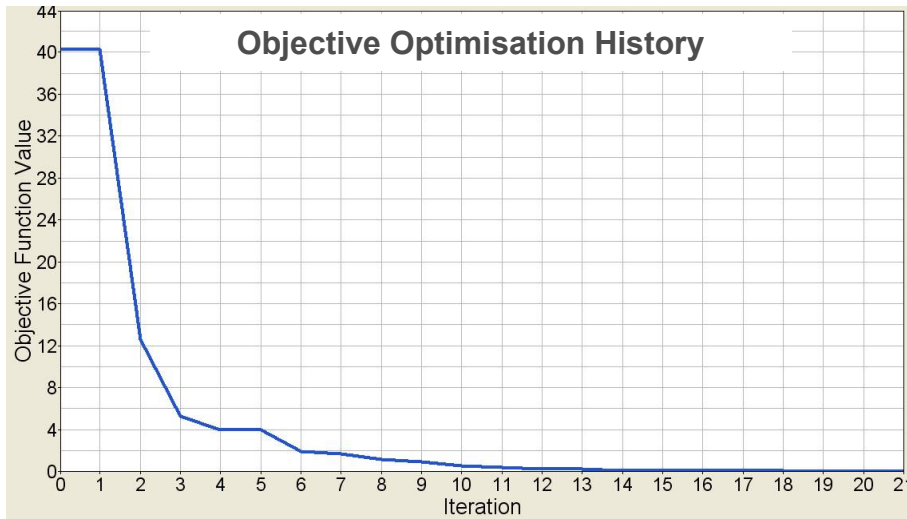


Figure 9: OptiStruct Objective Function Optimisation History

3.6 Step 5: Optimisation Results

By adopting the optimised settings of the design variables, the percentage difference to test data was significantly improved over baseline results. **Figure 10** shows the percentage difference to test for the first 10 modes as a comparison to baseline results.

Future door CAE predictions could adopt the variable settings obtained from the optimisation analysis for improved accuracy of results.

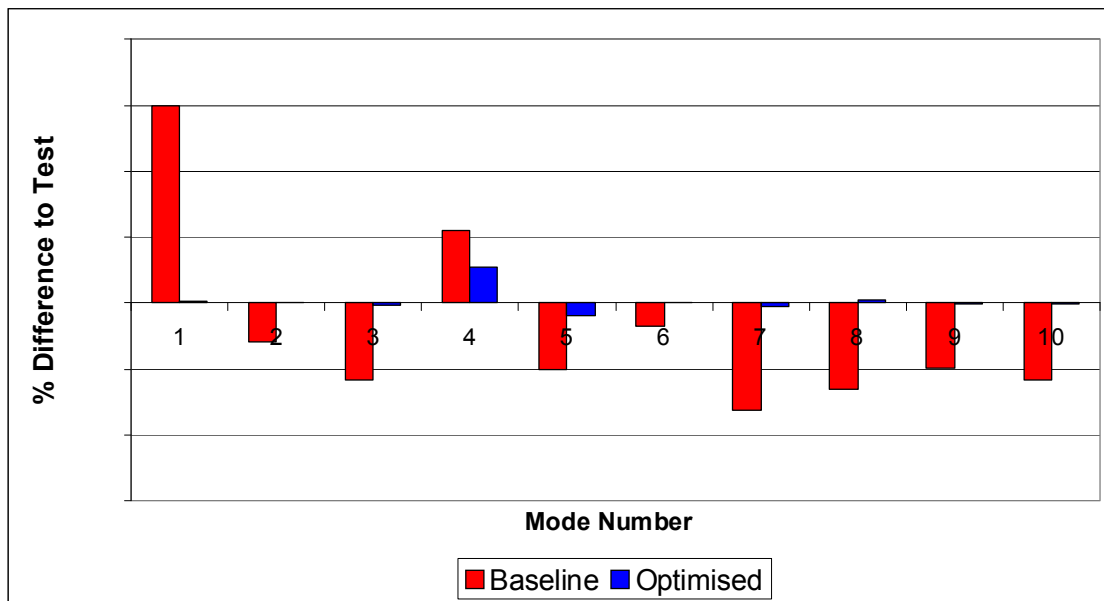


Figure 10: CAE Model Frequency Predictions Optimised and Baseline Results as a % Difference to Test Results, for the First 10 Modes.

4.0 Conclusions

In part 1, the door example demonstrated the process used to derive efficient excitation locations. In this example X, Y, and Z directions were defined as excitations at each candidate location. This approach can be adopted for all cases to ensure all potential excitation directions are examined. However, in the light of HyperStudy results, many of the

X and Z excitations did not produce high levels of response and could have therefore been omitted at the beginning of the analysis in favour of selecting more candidate locations. Consideration of candidate location and excitation direction may therefore be of benefit to ensure sufficient candidate locations have been selected and potentially redundant excitation directions are omitted.

As a general conclusion, the use of HyperWorks to reduce modal testing time by eliminating many un-necessary excitation points and identifying efficient excitation locations has been described and demonstrated.

In part 2, it was shown that OptiStruct enabled improved modal correlation by adjusting a number of variables against a single, but complex, objective measure. The improved correlation was achieved in a single optimisation analysis thereby significantly reducing the number of CAE iterations and man hours that would be required to achieve the same results through a manual variable modifications process.

Derived variable settings could be applied in future CAE modal simulations to improve the accuracy of predictions for multiple modes.

5.0 References

- [1] **Altair OptiStruct v9**, Altair Engineering, 2009
- [2] **Altair HyperStudy v9**, Altair Engineering, 2009