AVDASI 2 Dynamics Testing: EMA Post Processing Tool

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1 Introduction

This document and the associated Matlab App (*postProc.m*) are provided to enable the EMA GVT activity for both the fuselage and wing AVDASI 2 Dynamics groups. This package supports the final data processing stages which are covered in "*AVDASI2 Dynamics Part 1: Introduction to EMA and GVT and Part 2: Introduction to FEA and EMA-FEA correlation*" presentation, mainly slides 12 and 13. The App offers a straightforward environment which supports the processing of the originally collected input-output time domain data (impact hammer and accelerometer time series) by allowing transformation to the FRFs, selection of data, adjusting the processing parameters (e.g., the frequency range within which the modes of interest are searched and fitted) and extraction of the identified modal parameters (i.e., natural frequencies, damping ratios and mode shape vectors).

The following sections provide a step-by-step guide for this part of the process as illustrated on a simple demonstration example of a cantilevered T-beam.

Warning: The App must be located in the same folder as your processed MAT file.

2 Basic process and methods

On running the code, the file explorer will allow selection and opening of the required data MAT file. Select the required data file and click open to run the application. It may take a few moments to open the app window:

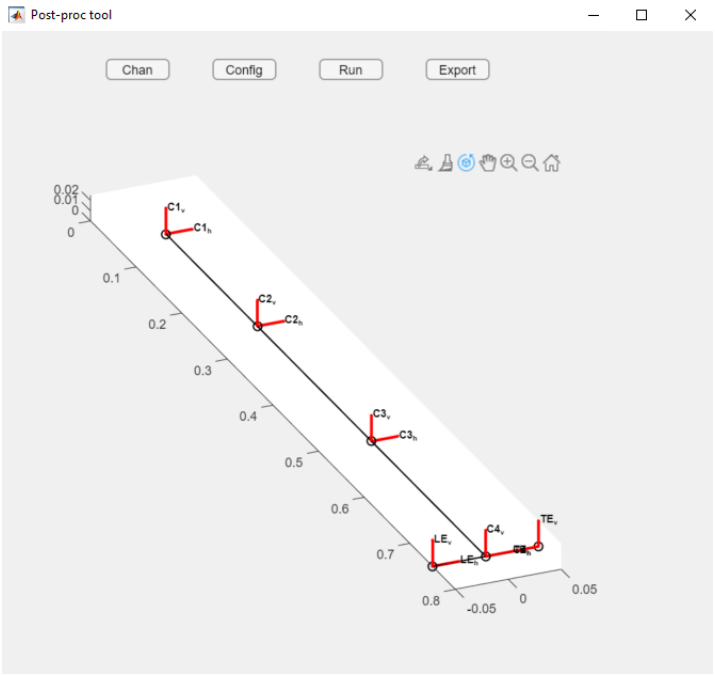

Figure 1: App window

The window shows the selected locations used to excite the structure (black 'O') and the red bars attached to these points indicate the directions in which the hammer was used at each of these points (e.g: The point C2 had two sets of impulses, vertically, C2_v and horizontally, C2_h).

The process flow of this app uses the average of the FRF's at each station and direction of excitation, between the accelerometer(s) and the inputs from the repeated impulses at each point. The averaged FRF's are then passed into MATLAB's *modalfit()* function[1] to fit a transfer function to the averaged FRF's collected experimentally (*see* slide 13). The fitted transfer function allows the extraction of modal properties and the mode shape itself. The quality of the fit is subject to the desired user settings and the collected data. For the present purpose, you are given the option to vary three main *modelfit()* parameters to tune its performance (these can be set through the 'Config' button).

The individual functionalities of the app buttons and the remainder of the interactive objects are described in Section 3. Below is an example of the processing stages that may be performed using the *T beam example* (you may try this with the attached T-beam example, using the associated data file '*NiData_TBeamDemo.mat*'):

1) View the FRFs from the repetitions at the selected places by clicking the red bars showing the excitation directions at each station **Figure *2*** (a) – see section 3.1. At the same time make a note of the placement of peaks which may be of interest

2) Using the **'Config'** button to tune the *modalfit()* parameters (section) to obtain a refined fit. You may check the quality of the fitted model by clicking on different red bars at different stations - **Figure *2*** (b). In this example, the first three modes are of interest. For this case, a frequency range of 5-25Hz with 6 modes set through **'Config'.**

(a) (b)

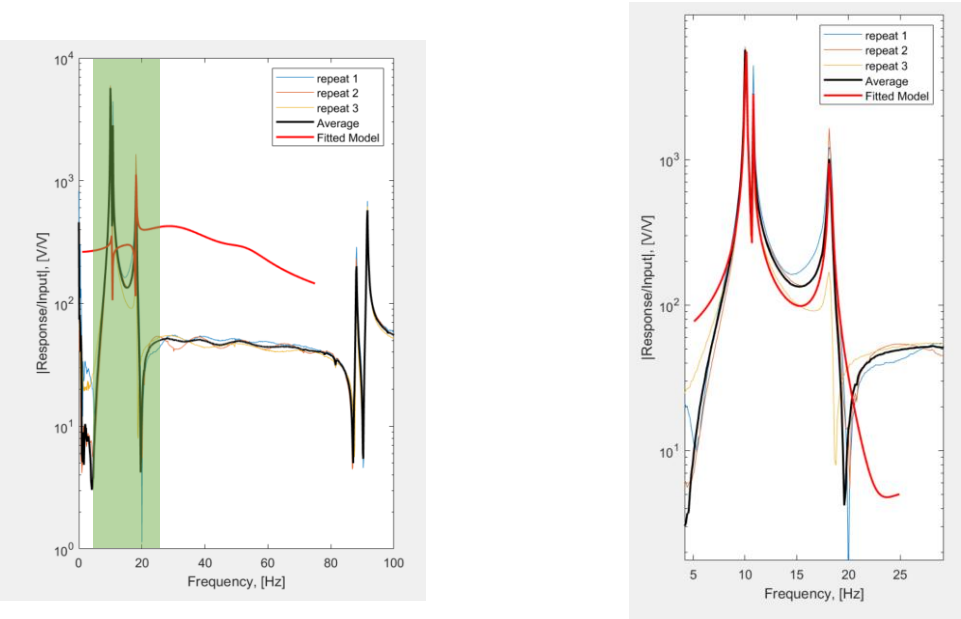

Figure 2: FRFs from case C4_v. (a) Prior to tuning fitting parameters. (b) With adjusted modalfit parameters

3) Once a satisfactory fit is obtained with the range of interest, click **'Run'** and follow the process described in section 3.4. For the current case, with the tuning parameters set in stage (2), the first three modes can be identified as shown in **Figure *6***. The identified modes may be

[1] Refer https://uk.mathworks.com/help/signal/ref/modalfit.html for more details.

recorded and saved. Repeat 2 and 3 if other individual or sets of peaks from different frequency ranges are of interest.

4) Click **'Export'** to save the selected modes and the fitted FRFs. You can use your own plotting functions using the exported data.

3 Functionalities

The app has 5 interactive elements: the 4 buttons (**'Run'**, **'Config'**, **'Chan'**, **'Export'**) and the clickable red bars showing the excitation directions at each station.

3.1 Clickable red bars

Clicking on an individual red bar showing the available impact direction(s) at each station on the main app window in **Figure *1*** opens the windows shown in **Figure *3***. In the shown example, the vertical excitation bar at station C1 ('C1_v') was clicked, as indicated by the Figure title in **Figure *3*** (a). The window in **Figure *3*** (b) shows the number of repeats recorded at this station the selected direction, in this case the 3 repetitions were recorded. The left hand side plot on window in **Figure *3*** (a) shows the FRFs generated from each of the repetitions, the average of the selected repeats and the result of the fitting from *modalfit()* as identified by its legend. The plot on the right shows the raw hammer inputs corresponding to each of the impulses[2] (this can be used to assess the quality of the hammer tapping).

(a) (b)

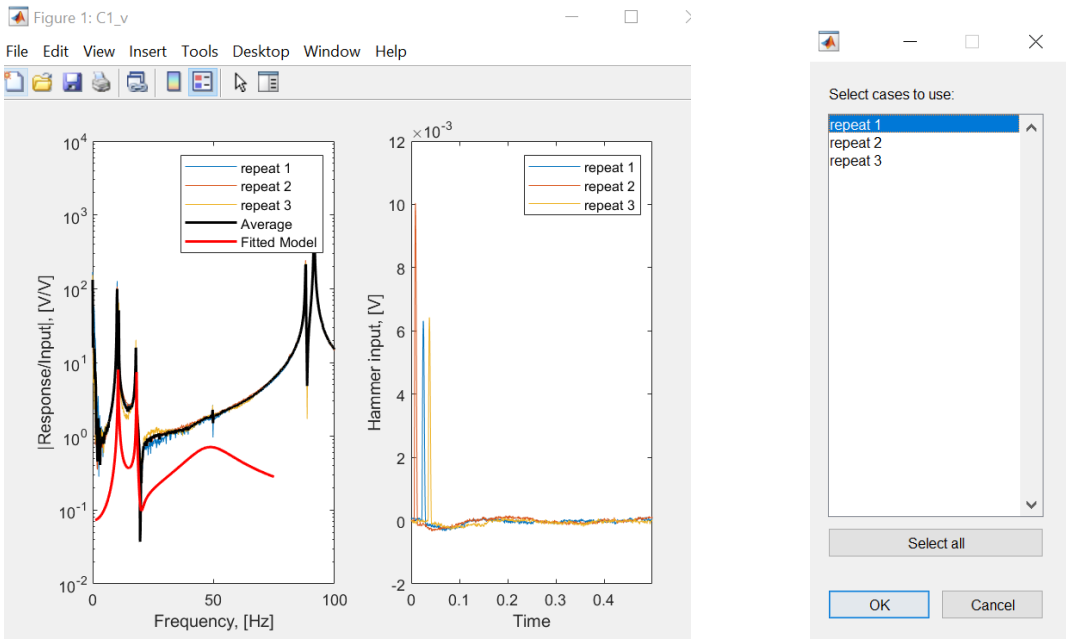

Figure 3: Windows opened on clicking a red bar indicating an excitation case. (a) Collected, averaged and fitted FRFs, (b) Tool to select repeated cases to retain for averaging

The window **Figure *3***(b) allows the user to select the desired set of repeats used for the averaging process (by default, it uses all of the repeats). If one of the repetitions can be identified as an outlier from **Figure *3***(a), the user can select all the repetitions excluding the one to be discarded and hit **'OK'**. If a refined selection is made, window **Figure *3*** (a) will close and re-open with the updated averages. If the existing selection is to be retained, simply click **'Cancel'** in **Figure *3***(b).

[2] For FRF computations, the only the content around the peak in the hammer input is retained, the remainder of the signal set to zero. This ensured that any spurious inputs generated by moving the hammer cable, etc during the collection period is omitted.

3.2 **'Chan'** button

Typically, during experimentation, two sensors were used, one in the In-plane/horizontal direction (IP) and one in the Out-Of-Plane/vertical direction (OOP). Clicking on the 'Chan' button allows the user to select which combination of sensors are to be used.

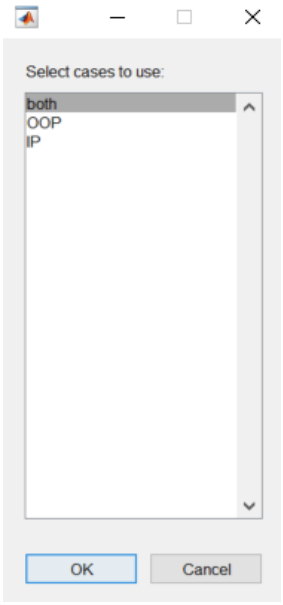

Figure 4: Window appearing on clicking 'Chan'

The options available on the above window are as follows:

- *'both'*: Combines the two sensors for further processing, as a new quantity that is sensitive to both the vertical and horizontal motions. This is the default setting.
- *'IP'*: Uses only the output of the horizontal sensor.
- *'OOP'*: Uses only the output of the vertical sensor.

The default setting is *'both'*. This is suggested if both the sensors were engaged simultaneously during the experiment as it allows meaningful mode shapes to be computed. However, if the experiment was carried out in two stages individually the corresponding setting must be selected (in these cases two data files will be provided, each engaging either the IP or the OOP sensor only).

3.3 **'Config'** button

The configure button allows the user to set the fitting settings used by *modalfit()* through the following window.

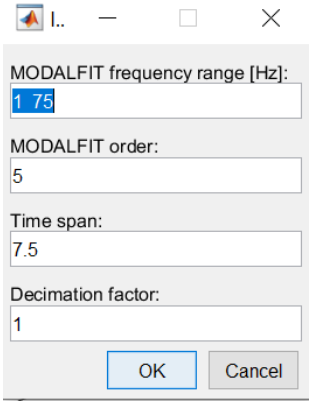

Figure 5: Window appearing on clicking 'Config'

In the above:

- **Frequency range** (1x2 input, default: 1-75Hz) defines the ranges of frequencies used for fitting the transfer function: the fitted FRF in **Figure *3***(a) spans this range.
- **MODALFIT order** (1x1 integer, default: 5) is a measure of the number of modes to be fitted within the selected range (*Note:* this number is based on your observations from the previous stages involving inspection of the measured FRFs – obtained after clicking the red bars).
- **Time span** (1x1 input, default 7.5s) the collection time in seconds (starting from the hammer impulse) to be used for processing. The experimental data was collected for 15s after each impulse. (*Note:* For instance, in the case of the damped modes with higher frequencies, the mode will decay significantly within a shorter time span and will continue to collect noise for the remaining period. The default value should be sufficient for your purpose. The option is available to adjust this if it is felt that that might help to improve the quality of the FRFs).

3.4 **'Run'** button

On clicking this button, the window shown in **Figure *6*** will appear. This is known as a *stabilisation diagram* – typically used as visual indication of the *physical* modes by presenting the "stable" columns of markers in the locations of the physical modes (as opposed to the spurious mathematical or processing peaks). (*Note:* in our case, it is used to present the automatically accepted modes / solutions generated by the methods used by *modalfit()*). See further explanation:

For the present purpose, this process of mode selection/acceptance/discovery is simplified. The figure overlays the frequencies identified by *modalfit()* as **clickable black lines**, on top of the average of all FRF's. User is simply expected to identify or use the lines that match a clear peak (i.e., the visible peak located in the proximity of a "stable" column of the markers). The line indicates a fitted physical mode of the structure. (*Note:* Avoid the cases of the lines placed in the proximity of the "unstable" modes typically characterised by the pattern of wandering markers).

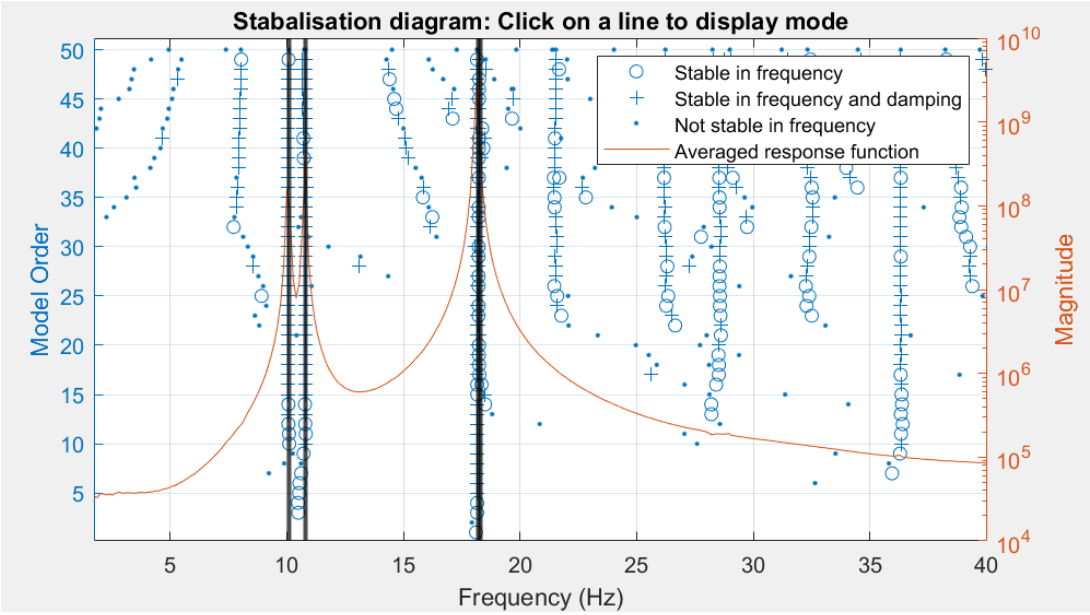

Figure 6: Stabilisation diagram appearing on clicking 'Run'

Clicking on a black line (e.g., below from the one just below 20Hz) opens the following:

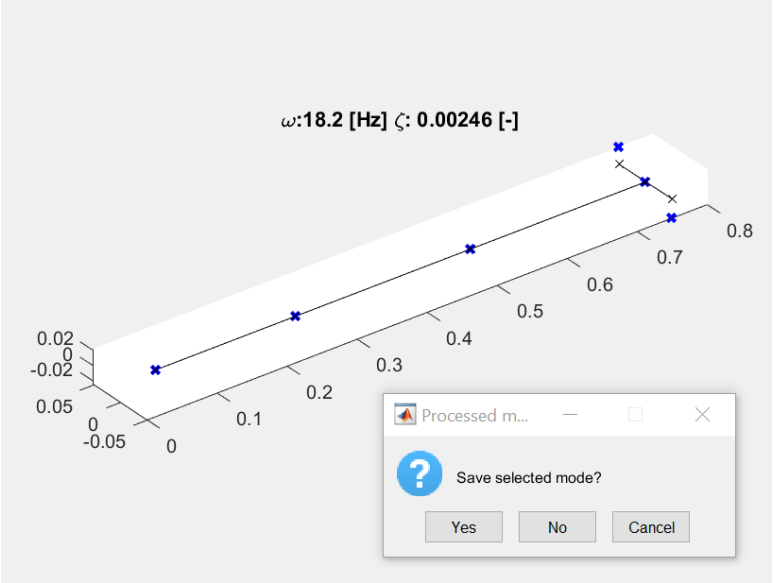

Figure 7: Example illustration of a mode shape and the option to save the mode on clicking a black line from Figure 6.

The figure visualised the *mode shape vector* associated with the selected black mode line (in the above case this mode implies the torsion mode) and it also offers information about the other modal properties – the natural frequency and modal damping. The user will be given the option to save the selected mode, if desired. If **'Yes'** is selected, an option will be provided to type in an identifier/name for the mode. When saving, the fitted FRFs linked with the current settings in '**Config**' are also saved. (*Note:* The mode is saved inside the App and can be later exported using the **'Export'** button).

Note: If an excitation was not carried for a certain direction at a certain station during the experiment, this point will not show any activity in that direction when mode shapes are displayed (i.e., zero value is assigned to that location and direction). The available excitation directions can be checked from the red bars available at each station in the main App window in **Figure *1***.

3.5 **'Export'** button

This allows the selected modes to be saved as a '.mat' file in a desired location. If a warning is presented on clicking '**Export**', it means that the user has not selected any modes as described above after clicking the '**Run**' button.

The saved file will have a cell array '**userData**' of size 1xN, N being the number of modes named and saved by the user through '**Run**'. Each of these cells will have the following structure:

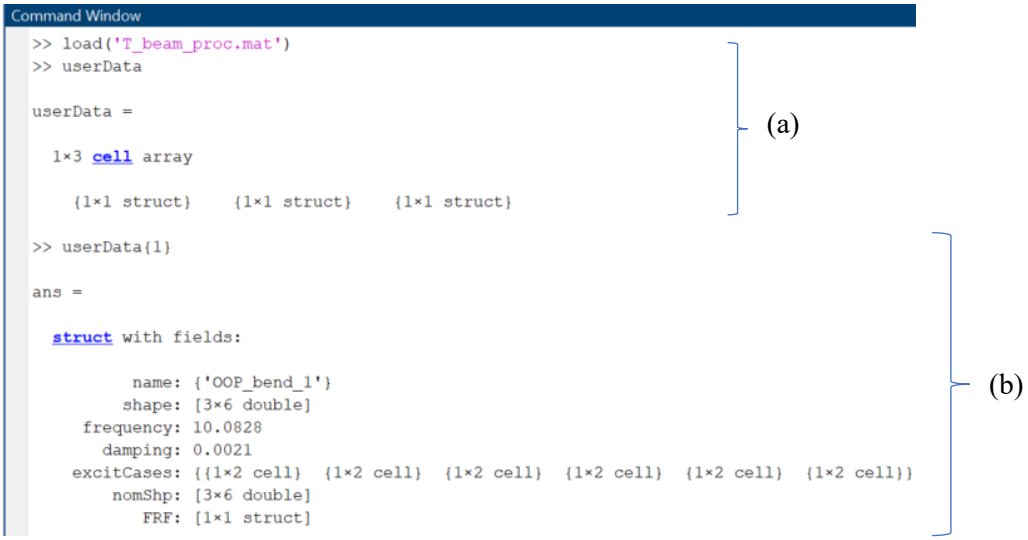

Figure 8: Example of the contents in the saved data file structure

- **name:** String identifier given by the user
- **frequency**, **damping**: corresponding to the mode
- **nomShp**: Excitation locations of the structure – 3xF, F being the number of unique excitation stations and each row giving the X,Y and Z coordinates
- **excitCases**: {1xF} cell array, each cell having the identifiers associating the multiple directions of impacts performed at each unique station.
- **shape**: modal deformation for the selected mode – 3xF, same as nomShp, each column giving the displacement of at the corresponding excitation station.
- **FRF** – structured array:
    - **FRF.frqVec**: 1xn array of n frequencies in Hz.
    - **FRF.avFRF**: n x 1 x J array of the averaged experimental FRFs collected from the J excitations, evaluated at the n frequencies in **FRF.frqVec**.
    - **FRF.fit**: n x 1 x J array of the fitted FRF by *modalfit()*, corresponding to the J excitations, evaluated at the n frequencies in **FRF.frqVec**.

Note that the FRFs are stored individually for each of the modes, based on the fitting parameters set through '**Config**' at the point of identification of the mode though '**Run**'. This is to allow for different *modalfit()* parameters to be set to identify groups of modes.

4 Conclusion

The primary entities obtained after this process are the natural frequencies and modal damping values. The mode shape visualisation figure can be used to attribute a character, nature, or type of vibration activity (e.g., bending, torsion, coupled, bending-bending, local bending or torsion, rigid body motion, etc.) to each of the selected modes.

The *natural frequencies* can be used for comparisons with the FE models (e.g., to validate or update these models) or the results of other EMA activities (e.g., to comment on the cross-part or design variations). The *modal damping* values can be used to comment on the extent and perhaps the origin of damping, in particular, when comparing the values for the same structure or across different structures. The *mode shapes* can be used to check and ensure the correct comparison between the

compared sets of vibration modes (e.g., comparing the first bending experimental mode with the first bending FE mode).

The exported data also contain the FRFs. *Optionally*, these data can also be used for the FRF-FRF comparisons between and across the experimental data and/or FE simulated data. It needs to be kept in mind that these are the acceleration FRFs in [Volts/Volts] because of the used types of the sensors and the absence of the measured channel calibration. When comparing with the FE FRFs, the correct type of the FRF needs to be generated for the correct input-output combination. To ensure the "unit matching", the measured or simulated FRFs can be multiplied and a suitable constant to achieve the acceptable vertical alignment of the compared FRFs.