PRE-TEST AND CORRELATION TOOLS FOR NVH IN META

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KEYWORDS –
Pre-test, correlation, modal, frequency, MAC

ABSTRACT –
In the first part of this paper, the new capability of META 17.1 to define good positions for accelerometers and a driving point is achieved on a cradle example. It is a pre-test which is a numerical evaluation before experimental tests to ensure that the excitation is well positioned to excite modes on the frequency range of interest and the accelerometers are well positioned to be able to distinguish the contribution of each mode in the measurements. Notice that the numerical model is assumed representative.

In a second part, the benefit of LC points (Loadcase points, introduced by BETA in version 17.0) are evaluated to facilitate the work of correlation, which include in particular the transformation of models and results to be consistent (units and coordinate system) between numerical and experimental data.

In a last part, others capabilities of META for correlation (MAC, COMAC, MACCo, FDAC, FRAC and FRAC correlator) are illustrated. Two numerical models are compared according to a limited number of DOF selected in the first part. A modelling difference has been introduced and correlation tools are used to try to locate it.

TECHNICAL PAPER -

1. PRE-TEST IN META

In NVH, to realize a work of correlation between the results of a numerical model and measures, the experimentation needs to be defined properly to catch the modal behaviours on the frequency range of interest. For that, the locations of accelerometers need to be selected in a way which allows to identify the contribution of each mode and the location of a driving point to excite as much as possible all these modes. Some new tools are available in META 17.1 to help the users to define these locations: the "Maximum off Diagonal MAC method" and the "Driving Point Residue method". The object of this part is to illustrate the use of these methods on a cradle example which was already studied for correlation in Vermont Des Roches [1] using PSA groupe's measures. The measures were obtained by an inverse method using only one tri-axes accelerometer on the "Driving point". Then, the hammer was used successively on each location retained for "accelerometers" to measure the FRF. Finally, modal shapes were deduced from FRF in Testlab. Notice that the pre-test was realized manually to define locations.

Model preparation
As a starting point, a dat Nastran file of the cradle model and the op2 file of the modal analysis result (SOL103) on all nodes are available. The units system for this model is in mm, T, s.
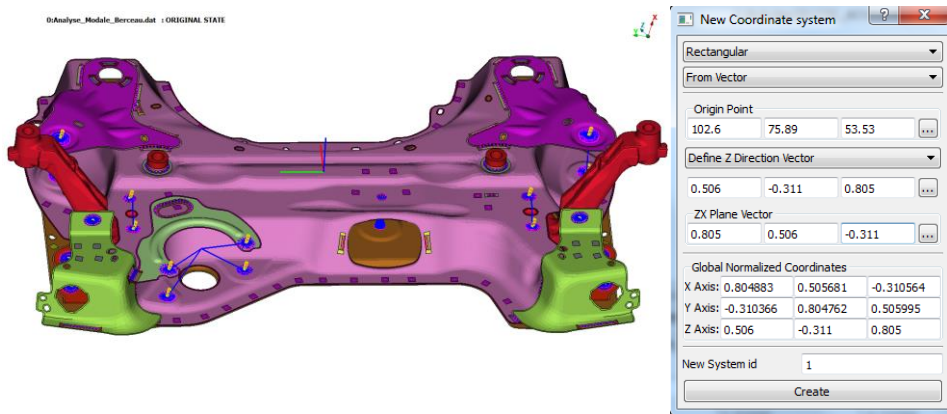
Figure 1 – Cradle model (left) and local coordinate system definition (right).

On this example, a local coordinate system (Figure 1) has to be defined, the one which will be used in experiments for accelerometers or impacts orientations. If needed, several local coordinate systems could be defined.

To prepare the next steps, two sets of DOF are defined: the first one for measured DOF that the user wants to impose, the second one for DOF which are candidates to be retained for accelerometers and driving point. The "List -> A/LC points" tool is used to define these sets. For the first set, the z-axis (local axis system) is chosen for the 3 points in yellow on Figure 2.
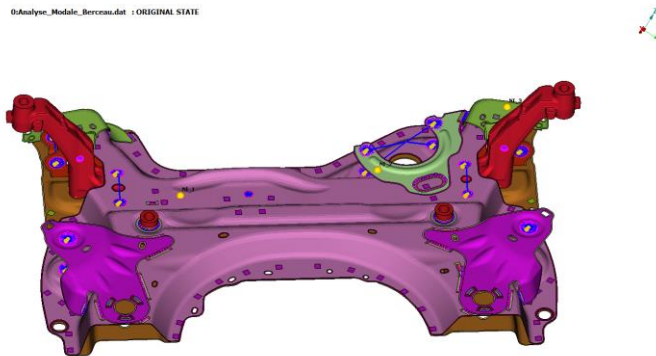

Figure 2 – The three LC points (in yellow) from the set of impose DOF.

For the other set, the "Uniform point distribution" option is used to create a distribution of 300 LC (LoadCase) points with the 3 translational DOF on each (Figure 3). Notice that the points are generated with the 6 DOF, but it is possible to modify the selected DOF by editing the list of point.
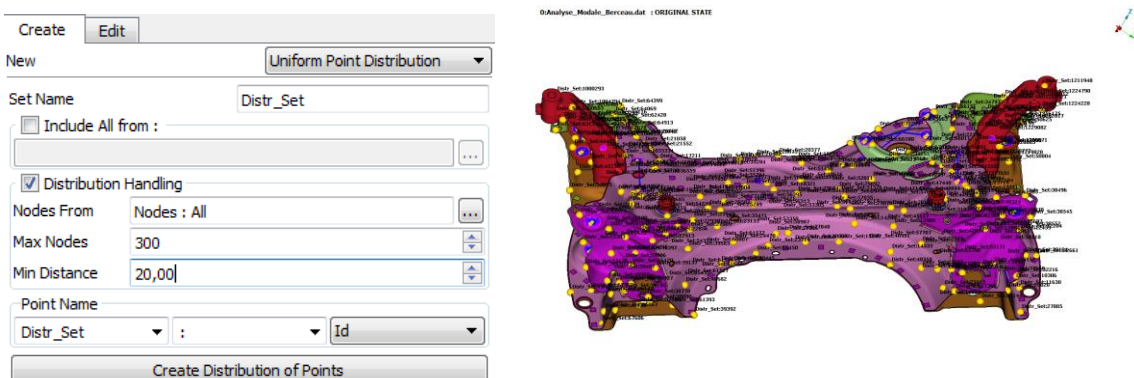

Figure 3 – Example of a uniform point distribution using META automation.

Of course, the local axis system defined previously (Figure 1) is also associated to each one of these LC points. It is done by editing the "Csys ID" of LC points. Same if it is not the case here, it is possible to define a different "Csys ID" for each LC point.

Selection of DOF for accelerometers

To select the set of DOF to use for accelerometers, the Maximum off diagonal MAC method, which is available for auto-MAC, is used. In the "FRF/Modal correlation tool", the "AutoCorrelation" option is selected, unit system is defined according to the data in the op2 file which is also loaded. To define node pairs (corresponding nodes between two models), the first set of DOF is used with corresponding LC points set for imposed DOF. By default, the coordinate system of LC points is the global coordinate system. Then, it was switched to "A/LC Point of Model 1" which allows to use the local axis systems of the LC points. Now, in "AutoMAC" tab, it is possible to add the second set of candidates DOF using the corresponding LC points. As previously, the coordinate system was modified from global to "A/LC Point of Model1". Before running the calculation, settings need to be defined properly. First, the option "Use Active DOFs" is selected to allow the use of the selected DOF only in LC points for MAC calculation. Also, in "AutoCorrelation Optimization options", the user can modify the target for the maximum extra-diagonal term, the used method and the maximum number of nodes or DOF according to the use of tri-axes or mono-axe accelerometers. In the example studied here, a maximum of 30 additional DOF is authorized with a target of 0.25 for MAC off-diagonal terms. Then, a simple click on "Optimize" allows to run the Maximum off Diagonal MAC method" and to get the result of Figure 4. The algorithm developed by BETA allows to select only around 13 DOF to add to the 3 initial DOF to reach the target. Then, a comparison of the initial MAC with the optimized one is directly available in META (see Figure 5). Different solutions are possible according to each run since a random process is applied to initialize the minimization process. Notice that if some retained DOF are not accessible for measurements, it is possible to exclude the DOF and restart the calculation.
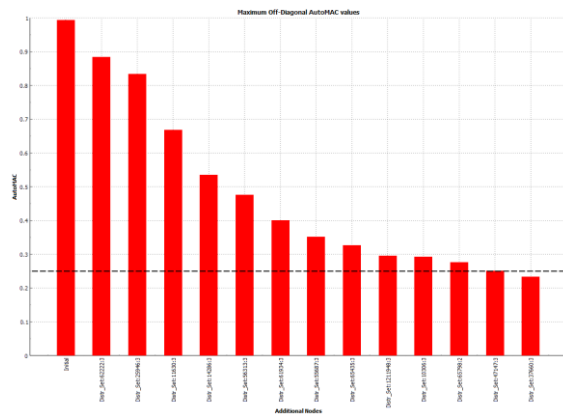

Figure 4 – Minimization of the maximum off diagonal terms of MAC on the 0.05-600Hz range.
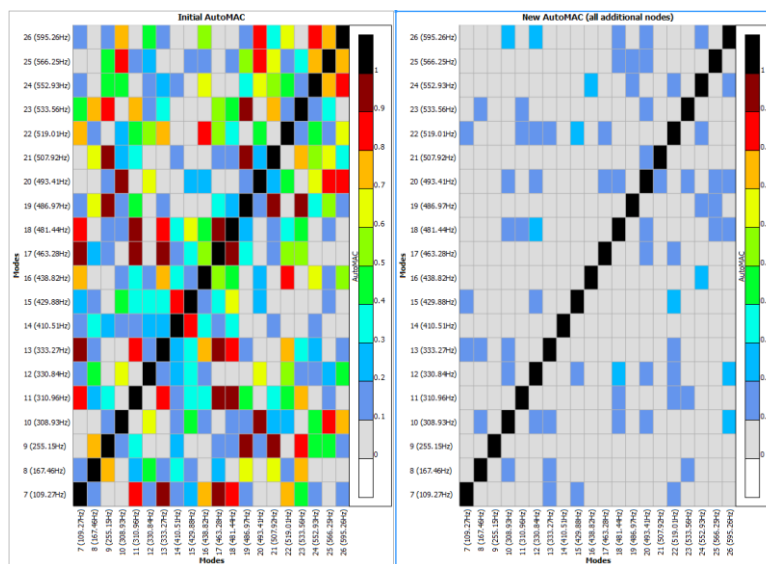
Figure 5 – Comparison of initial auto-MAC with MAC resulting from Maximum off diagonal MAC method.

META offers the possibility to move the LC Points attached to the 13 retained DOF in the node pairs list to get a final set of 16 DOF. This is a good solution to apply the Driving Point Residue (DPR) method on the remaining LC points. Also, the user can create a visual mesh based on retained LC points for measurements. For this, the "save as" button can be used to save node pairs as LC points in an alc_aux. Then, using the "List -> Display Mesh" tool, it is possible to create a visualisation mesh based on the LC points set.
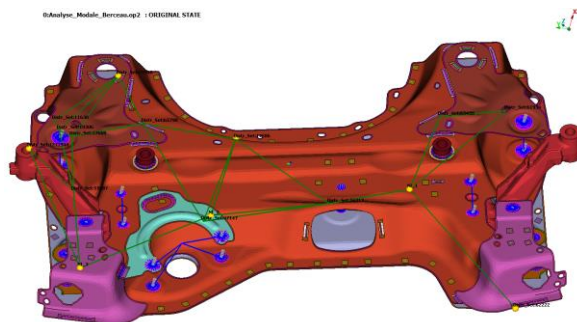

Figure 6 – Example of visualisation mesh created by META between LC points.

<u>Selection of DOF for excitation</u>

Then, the additional list can still be used to evaluate which are the best DOF of remaining LC points to be used as a driving point. In settings, a criterion proportional to the acceleration and an ordering of DOF according to a weighted average are selected. To learn more on this criterion, the reader can refer to Imamovic [2]. For each mode r, acceleration on dof i is about proportional to $\frac{\phi_{i,r}\phi_{i,r}}{\eta_r}$ where $\eta_r = \frac{2\xi_r}{\omega_r}$. As the modal damping ξ_r is an unknown in a real eigenvalues analysis, the modal coefficient on dof i is retained as proportional to $\frac{\phi_{i,r}\phi_{i,r}\omega_r}{2}$.

To select a DOF which allows a good compromise on the level of excitation for all retained modes, the weighted average of the acceleration criterion was used. A choice according to the minimum, maximum or average is also possible.
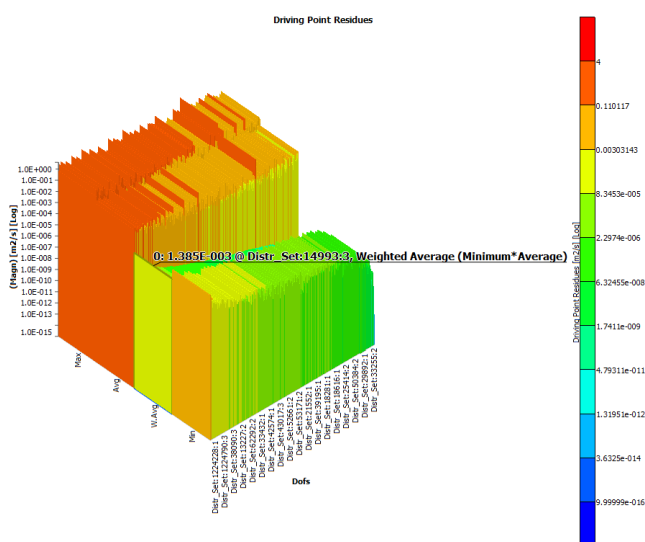
Figure 7 – Result of DPR with an ordering according to weighted average.

The DOF 3 of node 14993 is the best according to DPR calculation to impose the excitation (Figure 7). However, perhaps another compromise should be chosen because of constraints as accessibility or geometric features. In the cradle case, perhaps that node 14993 is too close from a geometric angle (Figure 8).
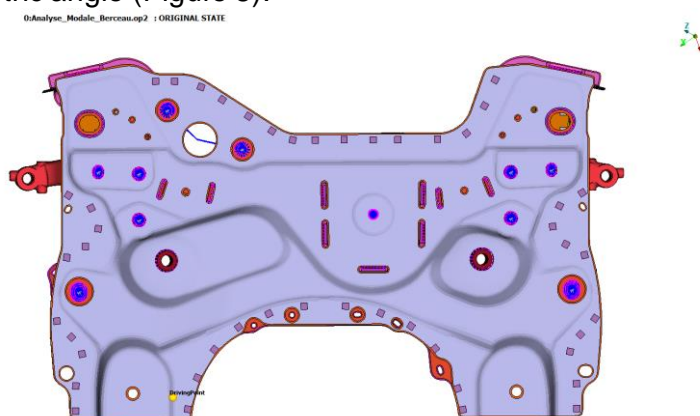

Figure 8 – Visualisation on cradle of LC point linked to node 14993.

BETA is able to develop scripts to help the users in this kind of situation. Then, if a new script could be develop to show on the model the best solutions for the driving point according to DPR calculation, it would be a good help for the users.

2. BENEFIT OF LC POINTS

In this part, the goal is to present some advantages in the use of LC points to prepare correlation between a numerical model and experiments.

For experiments files, a new META feature is available in case the user gets:

- an unv file with the visual mesh and the local coordinate systems used for measurements,
- a map file which allows to associate labels to nodes Id.

In this case, META allows to read both files and will associate automatically labels and nodes from map file with local coordinate systems in unv file. Then, the user can create directly an alc_aux file where LC points have the information on names and local axis systems. A good illustration of the interest of this kind of functionality is on a windscreen (Figure 9).
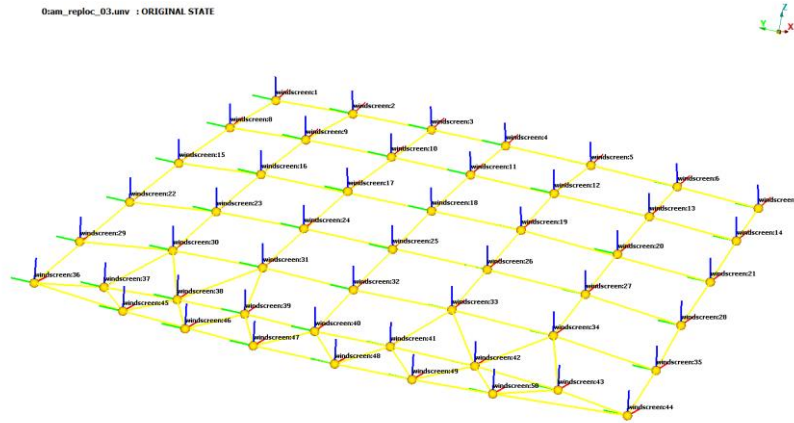
Figure 9 – Visual mesh of the windscreen with local coordinate systems.

Measurements are done orthogonally to the windscreen and a specific local coordinate system is defined for each point with a z-axis normal to the surface. After creating the alc_aux file, the user just has to modify DOF to only retain the z-axis, the local coordinate systems are already associated to LC points by META.

For the cradle example, the map file and the definition of the local coordinate system in the unv are not available, measures have been done in the global axis system. However, as a test case, a transformation has been applied on the finite element model (Figure 10). Then, results of the real eigenvalues analysis are in a local coordinate system and experimental mesh has been scaled to fit with the numerical model (Figure 11).
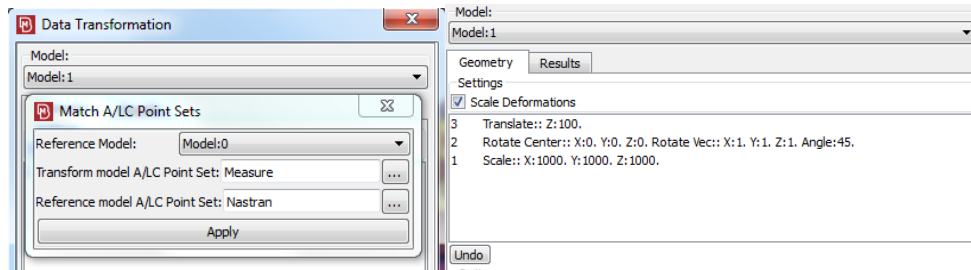

Figure 10 – Data transformation using LC point sets (left) or geometric transformations (right).
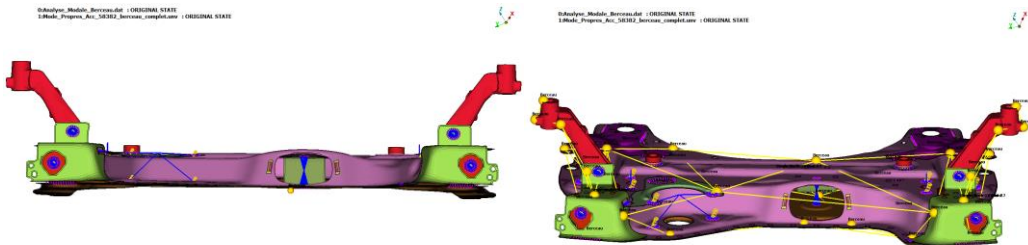
Figure 11 – Nastran and experimental mesh before (left) and after (right) transformation.

To finish, LC points can be used to define node pairs. Notice that for each LC point, it is possible to define the DOF to retain in the correlation calculations. It is a new feature introduced in META 17. Thus, it was possible to realize the MAC calculation which was the starting point in the correlation study of Vermot des Roches [1] and the result is the expected one (Figure 12).

Figure 12 – MAC between Nastran calculation and measurements.

3. CORRELATION IN META

To evaluate the correlation tools in META, two different models of the cradle are defined and a difference is introduced, a connexion was removed on the right model in Figure 13.
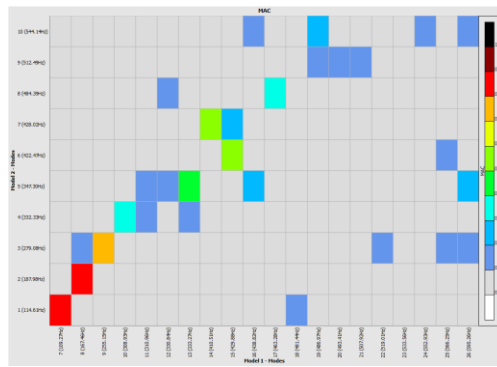

Figure 13 – Reference model (left) and modified model (right). A connexion is missing in the modified model.

The correlation tools are used to attempt to identify and localize the modelling difference. Notice that only the DOF retained previously in pre-test are used for correlation computations (see Figure 5 for auto-MAC reference). That defines a situation comparable to a correlation between numerical results and measurements where few DOF are available.

Modal criteria

First, the Modal Assurance Criteria (MAC) and the COordinate Modal Assurance Criteria (COMAC) are applied on range 0.05-600Hz (Figure 14). The MAC allows a check of the collinearity between modal shapes. The COMAC attempts to identify DOF which contribute negatively to a low value of MAC for mode pairs identified by MAC calculation. The reader can refer to Allemang [3] for more information on these methods.
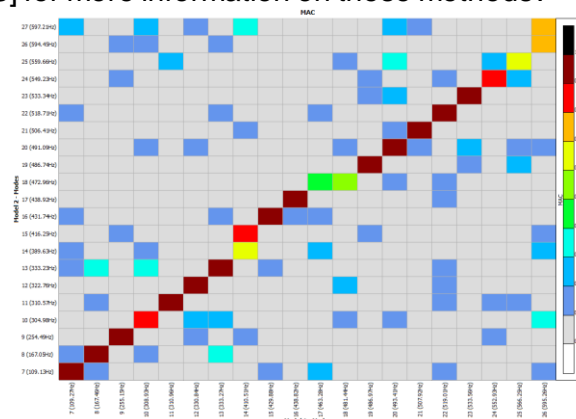

Figure 14 – MAC between both cradle models.

From MAC, it is possible to deduce that there are some correlation issues, but it is not possible to localize their origin. The COMAC should help to localize them, but that doesn't seem so simple according to the results of Figure 15.
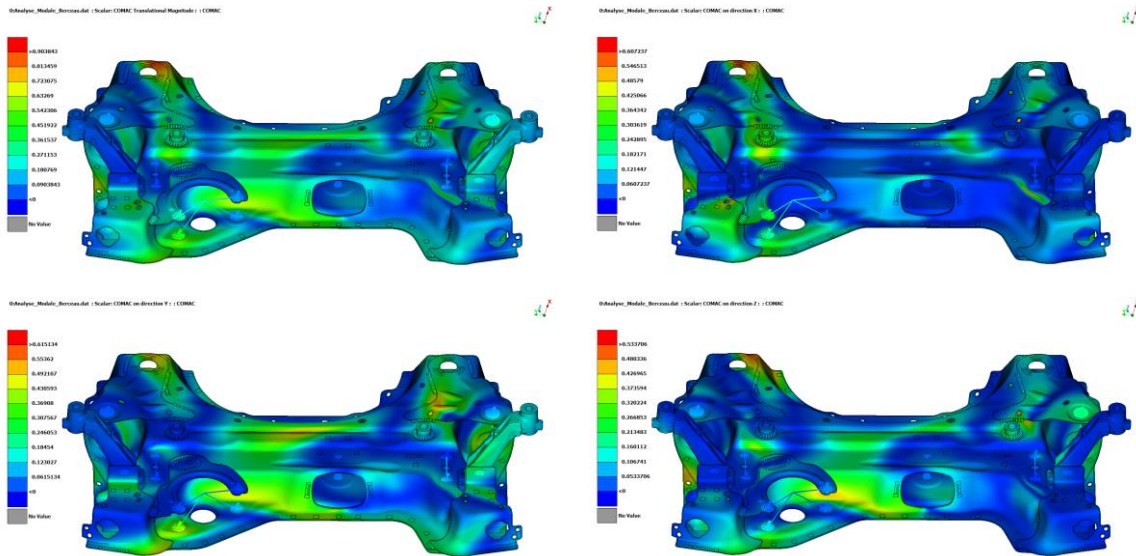

Figure 15 – COMAC between both cradle models on mode pairs with a MAC coefficient superior to 0.5 and a frequency tolerance of 20%.

In retained DOF, there is no one according to local X-axis and only one according to Y-axis. The post-processing by axis is probably done according to the global axis system and it is not necessary the best way to do it. For the post processing according to magnitude, the extrapolation leads to values which are really higher than in post processing according to axes (see color scales which are in agreement with values on the mesh). Also, the table with the effective COMAC results (Table 1) by DOF in the local coordinate system doesn't give any value superior to 0.5. These observation leads to an interrogation on the validity of the extrapolation when few DOF are available. Finally, the COMAC coefficients for the two closest nodes (62222 and 17968) from modelling difference are weak, but not the worst. Then, it is difficult to localize the modelling difference by COMAC results.

Node Pair	Dofs	Dofs Coord.Sys.	COMAC Y	COMAC Z
10306-10306	3	A/LC Point of Model 1	0	0.119994
11630-11630	3	A/LC Point of Model 1	0	0.0881125
14286-14286	3	A/LC Point of Model 1	0	0.0235139
17968-17968	3	A/LC Point of Model 1	0	0.0126841
25946-25946	3	A/LC Point of Model 1	0	0.369767
37660-37660	3	A/LC Point of Model 1	0	0.000517816
47147-47147	3	A/LC Point of Model 1	0	0.259059
55687-55687	3	A/LC Point of Model 1	0	2.46693e007
56313-56313	3	A/LC Point of Model 1	0	0.00313368
61934-61934	3	A/LC Point of Model 1	0	0.0184518
62222-62222	3	A/LC Point of Model 1	0	0.0187918
64814-64814	3	A/LC Point of Model 1	0	0.0821
65435-65435	3	A/LC Point of Model 1	0	0.494338
65798-65798	2	A/LC Point of Model 1	0.123025	0
66069-66069	3	A/LC Point of Model 1	0	0.0078697
1211948-1211948	3	A/LC Point of Model 1	0	0.0356526

Table 1 – COMAC table for retained DOF in local coordinate system.

Another available tool in META is the MAC Contribution (MACCo) which can be applied individually on mode pairs. This tool allows to rank the worst DOF by the MAC value improvement if they were removed. From results on mode pairs 14-14 and 14-15 (Figure 16), the method allows to detect that DOF 3 of nodes 62222 ("Distr_set:62222") and 17968 ("NI_1") are the worst and it is effectively the 2 DOF which are the closest of the modelling difference. This tool could also be used to detect some anomalies in measures which could

be due to material issues or operator mistakes (on a sign to define by the operator for example).
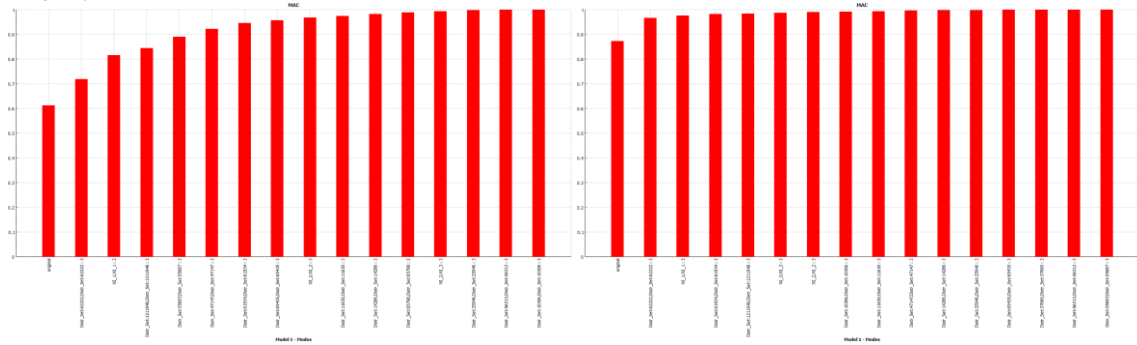

Figure 16 – MACCo on mode pair 14-14 (left) and 14-15 (right).

According to this result, MACCo is an interesting method to analyse mode pairs which doesn't fit together correctly.

FRF criteria

Main interest of FRF criteria is probably to be able to use directly measured data. For modal criteria, modes frequencies and modal shapes need to be extracted from FRF and the quality of this work is dependent of some operator choices.

To evaluate correlation tools for FRF, the "Modal response" tool of META was used to calculate the FRF on retained DOF according to a Nastran modal analysis. The load was imposed on the driving point retained at the end of the pre-test part.

For FRF, the Frequency Domain Assurance Criterion (FDAC) is quite similar to MAC and gives a global result where the collinearity between Ordinary Deformation Shapes (ODS) is evaluated.
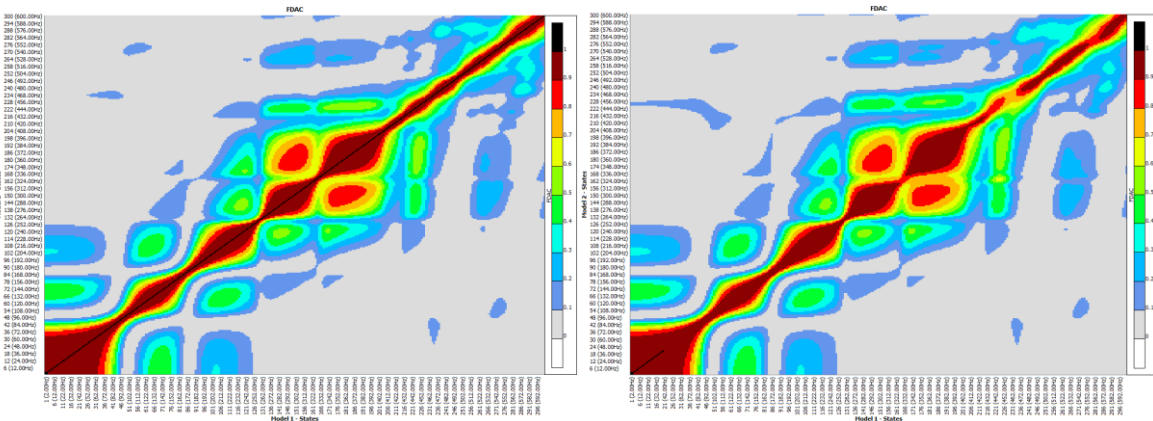

Figure 17 – Auto-FDAC (left) and FDAC (right).

By comparison between auto-FDAC and FDAC (Figure 17), some frequency ranges are sufficiently different and a local analysis on DOF can be realized using FRAC.

On Table 2, FRAC was computed on different ranges. The larger range (2-600Hz) allows to detect that DOF on nodes 62222 and 17968 have the worst FRAC coefficients. For ranges 380-430Hz or 400-500Hz, the DOF of node 62222 is still identified as the worst but not the one on node 17968 which have a quite good FRAC coefficient. The range 380-430Hz was choose to compare the result with MACCo on mode pairs 14-14 and 14-15 (Figure 16). Althrough MACCo was able to detect a bad correlation on the retained DOF for node 17968, it is not the case for the FRAC, probably in reason of interferences with other modes.

Node1	Node2	Dofs	Dofs Coord.Sys.	FRAC Y	FRAC Z
10306	10306	3	A/LC Point of Model 1	0	0.98468
11630	11630	3	A/LC Point of Model 1	0	0.975391
14286	14286	3	A/LC Point of Model 1	0	0.973146
17968	17968	3	A/LC Point of Model 1	0	0.734731

Node1	Node2	Dof:	Dofs Coord.Sys.	FRAC Y	FRAC Z
10306	10306	3	A/LC Point of Model 1	0	0.966431
11630	11630	3	A/LC Point of Model 1	0	0.963392
14286	14286	3	A/LC Point of Model 1	0	0.970618
17968	17968	3	A/LC Point of Model 1	0	0.954677

Node1	Node2	Dofs	Dofs Coord.Sys.	FRAC Y	FRAC Z
25946	25946	3	A/LC Point of Model 1	0	0.993636
37660	37660	3	A/LC Point of Model 1	0	0.949651
47147	47147	3	A/LC Point of Model 1	0	0.974465
55687	55687	3	A/LC Point of Model 1	0	0.962879
56313	56313	3	A/LC Point of Model 1	0	0.946985
61934	61934	3	A/LC Point of Model 1	0	0.920287
62222	62222	3	A/LC Point of Model 1	0	0.651064
64814	64814	3	A/LC Point of Model 1	0	0.953323
65435	65435	3	A/LC Point of Model 1	0	0.903172
65798	65798	2	A/LC Point of Model 1	0.990435	0
66069	66069	3	A/LC Point of Model 1	0	0.877907
1211948	1211948	3	A/LC Point of Model 1	0	0.943674

(a)

Node1	Node2	Dofs	Dofs Coord.Sys.	FRAC Y	FRAC Z
25946	25946	3	A/LC Point of Model 1	0	0.967854
37660	37660	3	A/LC Point of Model 1	0	0.950501
47147	47147	3	A/LC Point of Model 1	0	0.992415
55687	55687	3	A/LC Point of Model 1	0	0.892678
56313	56313	3	A/LC Point of Model 1	0	0.966602
61934	61934	3	A/LC Point of Model 1	0	0.94732
62222	62222	3	A/LC Point of Model 1	0	0.474828
64814	64814	3	A/LC Point of Model 1	0	0.763415
65435	65435	3	A/LC Point of Model 1	0	0.752311
65798	65798	2	A/LC Point of Model 1	0.969071	0
66069	66069	3	A/LC Point of Model 1	0	0.993323
1211948	1211948	3	A/LC Point of Model 1	0	0.839246

(b)

| Node1	Node2	Dofs	Dofs Coord.Sys.	FRAC Y	FRAC Z
10306	10306	3	A/LC Point of Model 1	0	0.984442
11630	11630	3	A/LC Point of Model 1	0	0.959429
14286	14286	3	A/LC Point of Model 1	0	0.994533
17968	17968	3	A/LC Point of Model 1	0	0.983781
25946	25946	3	A/LC Point of Model 1	0	0.998199
37660	37660	3	A/LC Point of Model 1	0	0.921158
47147	47147	3	A/LC Point of Model 1	0	0.941884
55687	55687	3	A/LC Point of Model 1	0	0.872972
56313	56313	3	A/LC Point of Model 1	0	0.873291
61934	61934	3	A/LC Point of Model 1	0	0.988412
62222	62222	3	A/LC Point of Model 1	0	0.797562
64814	64814	3	A/LC Point of Model 1	0	0.979637
65435	65435	3	A/LC Point of Model 1	0	0.994603
65798	65798	2	A/LC Point of Model 1	0.970245	0
66069	66069	3	A/LC Point of Model 1	0	0.982359
1211948	1211948	3	A/LC Point of Model 1	0	0.840748

(c)

Table 2 – FRAC result on range 2-600Hz (a), 400-500Hz (b) and 380-430Hz (c).

To finish, a last tool called "FRAC correlator" is available in META. This tool allows to evaluate the effects of a factor applied on the frequency range associated to the FRF for one of the two models (Figure 18). Same if this tool is not done for that, the post processing on frequency range 2-600Hz allows to visualize the poor result on FRAC for retained DOF on nodes 62222 and 17968. The variations according to the frequency factor allow to tell that the issue cannot be fixed by a simple tuning on stiffness or mass.

For narrower frequency ranges (380-430Hz and 400-500Hz), it is more difficult to identify the worst DOF and a frequency factor exists to reach a good correlation. In this case, the user could have the temptation to tune the material properties in the model. However, it would be a bad decision in this case since that wouldn't solve the modelling issue. Then, the FRAC correlation tool has to be used with caution and the user experience stay important.
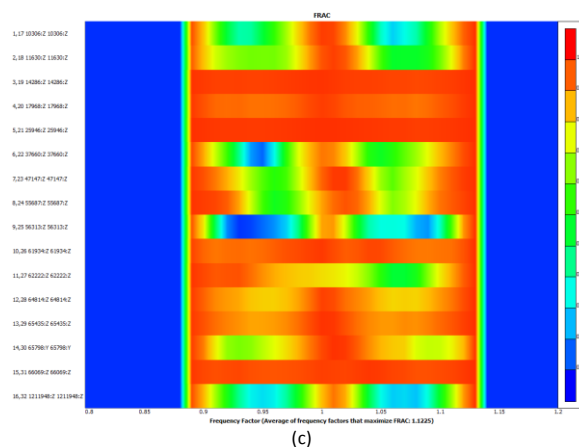

(a)

(b)

(c)
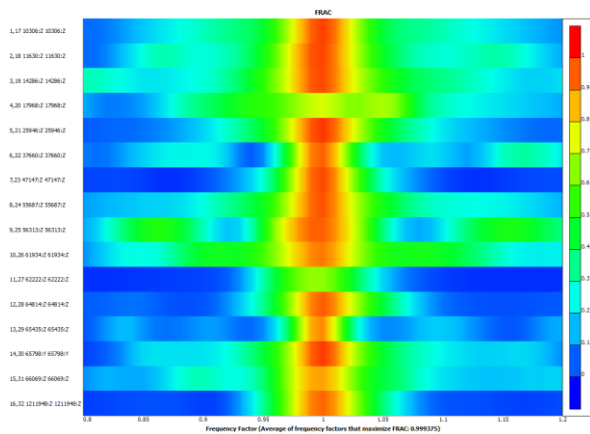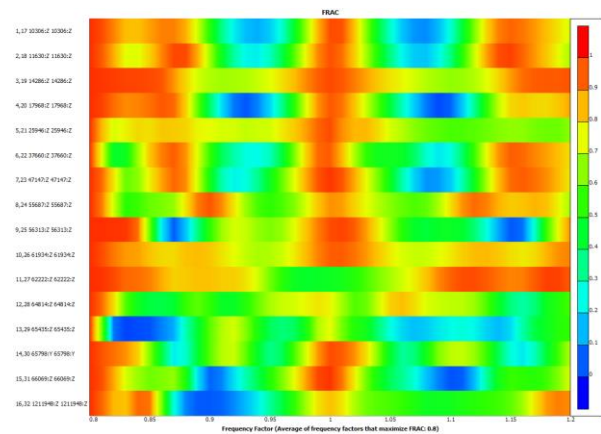
Figure 18 – FRAC correlator result on range 2-600Hz (a), 400-500Hz (b) and 380-430Hz (c).

4. CONCLUSIONS

META 17.1 offers good tools to define accelerometers and driving point positions. The "maximum off diagonal terms of MAC" method is a good way to select a reasonable number of positions for accelerometers according to the auto-MAC result.

Also, LC points introduce new capabilities to fit the geometries, to define node pairs, to introduce local coordinate systems and select DOF to retain. LC points can also be generated easily in reading .unv and .map from Testlab, which saves time to users, especially when there are many different local coordinate systems.

Finally, for a selection of DOF, the correlation tools were used between two closed models which only differ by a connexion.

In the modal correlation tools, the MAC and MACCo tools allow to analyse by mode pair and to detect the DOF which are the closest from the modelling difference. The COMAC which is applied on a selection of mode pairs is more difficult to interpret. Two questions in the attention of BETA. Could the 3D post processing takes in consideration the local coordinate systems? Which is the validity of the expansion with few DOF? Notice that a work on modal shapes expansion could also be an interesting subject, same if it was not discussed in this paper.

In the FRF correlation tools, FRAC and FRAC correlator gave an interesting result on a wide frequency range (2-600Hz) to detect the DOF which are the closest from the modelling difference. However, the results are less good on a narrow frequency range (380-430Hz or 400-500Hz).

Then, different tools are available but the user experience stay an important parameter to succeed to identify modelling issues and improve correlation in a right way.

ACKNOWLEDGMENT

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