MODAL SPACE - IN OUR OWN LITTLE WORLD *by Pete Avitabile*

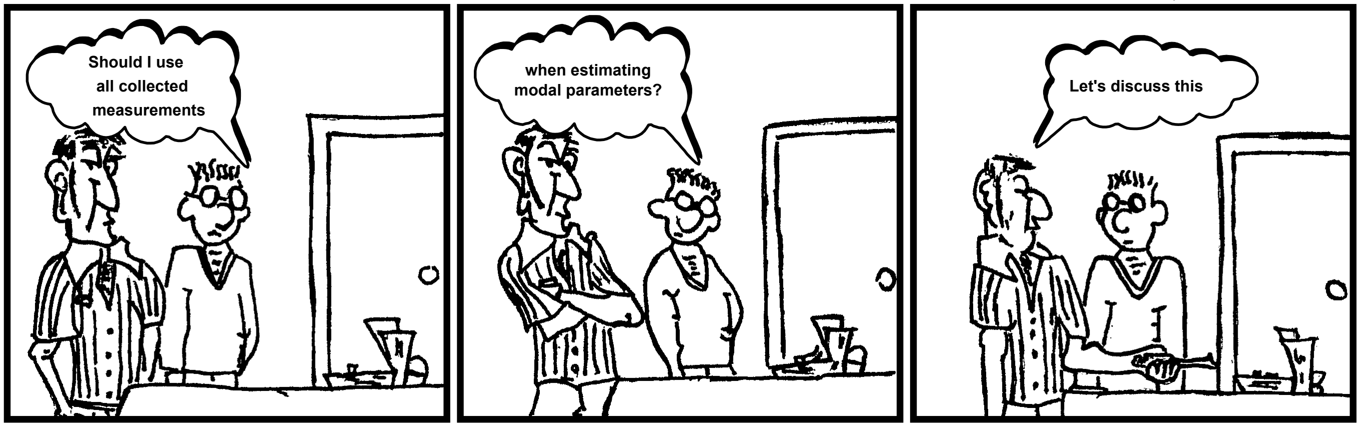

Illustration by Mike Avitabile

Should I use all collected measurements when estimating modal parameters?
Let's discuss this.

This is a very good question. There is no reason to not include all the data collected providing that the data is well measured and consistently related. Providing that there is good dynamic range, with accurate sensitive transducers and all modes are well excited from all reference points and at all the response locations, then, of course, all the data can be used for estimating modal parameters.

But as I said that mouthful of requirements, I could tell from the expression on your face that it is ***highly unlikely*** that ***all*** your measurements meet that requirement. In the past quarter century, I know that I have ***never*** had that happen in any test I have conducted or been associated with - so join the club! What I just described is a measurement situation that will likely only occur with an analytical model with infinite dynamic range and infinite frequency resolution. The real fact is that from a practical standpoint, this will probably never happen. So let's discuss the reality of the situation and discuss some practical approaches to minimize some of the measurement shortcomings.

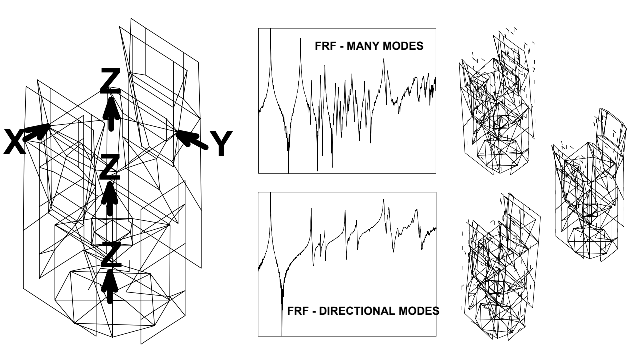

Figure 1 - Aerospace Structure with FRFs and Several Modes

As an example of a common measurement problem, I will use a test that was run many years ago on an aerospace structure that had very directional modes as well as numerous local modes. The structure is shown in Figure 1 along with some typical FRFs. Notice that the lower FRF only shows a few modes but the upper FRF shows all the modes of the structure. Actually, the problem isn't just an aerospace problem but a general problem that can be seen in many structures we test. In fact, the measurements shown are typical of those that could be from almost any structure subjected to modal testing.

The particular structure shown had several bending and torsional lower order modes followed by many local modes with bending, torsion, in-phase, out-of-phase types of modes for the panels and peripheral equipment on the structure. The actual structure was tested using 5 independent shaker excitations (three vertical and two separate horizontal directions).

The first mode of the structure consisted of bending in the x-direction with almost no response in the y-direction. Obviously, the shaker in the x-direction can do a very good job of exciting the x-direction modes but the shaker in the y-direction does not excite the structure in the x-direction very well at all. So the measurements obtained from the y shaker are obviously going to be very poor due to the lack of participation of the first mode in the y-direction.

On the other hand, the second mode of the structure consisted of bending in the y-direction with almost no response in the x-direction. Here the opposite is true from that just discussed. The y shaker can do a very good job of exciting the structure in the y-direction but the shaker in the x-direction cannot excite the structure in the y-direction. But both shakers can do a very good job of exciting the torsional mode from both shaker locations. This directly implies that all of the measurements will not be measured with the same degree of accuracy for each mode.

During the MIMO excitation with 5 shakers, all of the FRFs are collected simultaneously but clearly not all of the modes are excited equally from each of the shaker locations. This is a physical reality of most test structures that is typically impossible to overcome. So how can all of this data be efficiently and accurately processed.

Most modal parameter estimation performed today, generally utilizes a two step process. First, the poles are estimated and then the residues or mode shapes are computed (once global poles have been extracted). With this in mind, the poles of the system do not need to be estimated using ***all*** the measurements collected. The poles can be estimated using only a subset of measured functions that best describe the poles of interest. Once the global poles have been estimated, then the residues or mode shapes can be extracted using all the measurement DOFs. (It is also not necessary to estimated residues for all references, especially if the references do not sufficiently excite all the modes). The selection of particular FRFs for the extraction of poles is schematically shown in Figure 2.

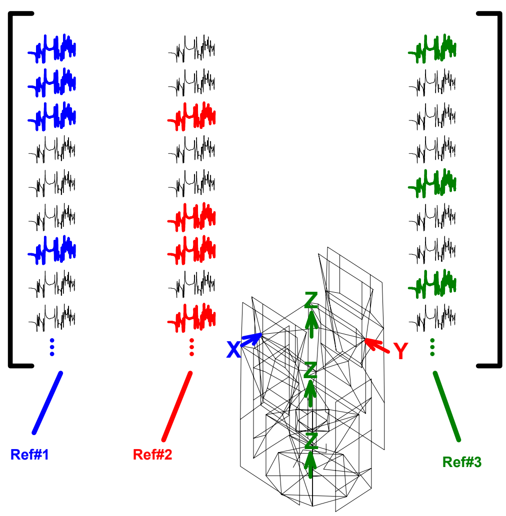

Figure 2 - Schematic Depiction of Measurement Selection

In the example discussed, the first x-bending mode was estimated using only the x-response location from the x-excitation location. Only the y-response locations were used for the y-excitation location for the y bending modes. But both x and y excitations with the x and y responses were used for the torsional mode. Notice that the z-direction excitation and response were ***not*** used for the estimation of any of these poles. This is because the z-excitation locations have a very hard time exciting either the x or y direction modes efficiently. While these references/excitations are necessary for the excitation of some of the higher frequency modes, these vertical excitations are not very good for the excitation of the lower order x and y direction modes. But, of course, once the poles are estimated, then the residues or mode shapes are estimated using all the measurements in the x, y and z directions - but only using the x and y shaker excitations for the x and y lower order modes.

During the modal parameter estimation process, extreme care needs to be exercised to extract the best possible poles to describe the system characteristics. However, many of the measurements and often times all of the references are not optimum for all the modes of the system. As an example, a large telescope structure was recently tested with 4 reference excitation locations. Clearly, the references were not all optimum for all the lower order directional modes of the structure. As a first pass on evaluating the data, all the FRFs from all the reference locations were used to extract poles and residues for the structure. Once parameters were selected, a synthesized FRF was generated and compared to the actual acquired measurement as part of the validation process. The synthesized and measured FRF are shown in Figure 3a. Please carefully note that this is ***not*** a good comparison of the measured and synthesized FRFs. However, after a very careful evaluation of the data and careful selection of measurements to extract the poles of the system (followed by residue extraction), a far better model was obtained. This is confirmed by the comparison of the synthesize and measured FRF shown in Figure 3b. Of course, this approach requires significant effort but the modal parameters are generally greatly improved.

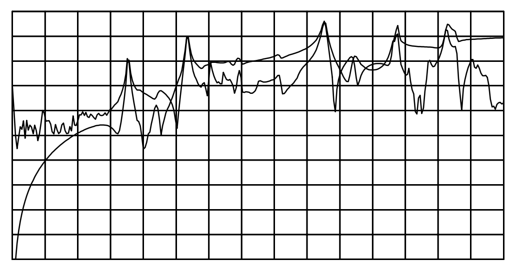

Figure 3a - Poor Extraction and Synthesis of FRFs

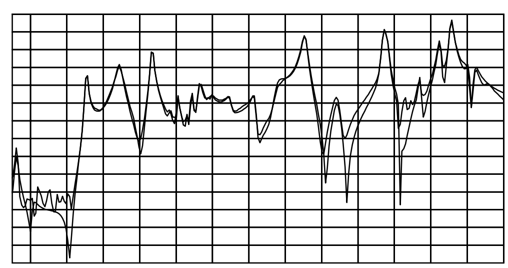

Figure 3b - Good Extraction and Synthesis of FRFs

I hope this explanation helps you to understand why it may not be necessary (or actually detrimental) to use all of the measured FRFs when extracting modal parameters. A careful selection of the best measured FRFs will generally produce much better global poles of the system for the modal parameter estimation process. If you have any other questions about modal analysis, just ask me.