MODAL SPACE - IN OUR OWN LITTLE WORLD

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What are some of the major mistakes people make in modal tests so I don't make the same ones.
Let's talk about some of them.

Well, there are many things I have seen over many years that are big mistakes that people have made during modal testing and analysis. Some of them are actually pretty funny and some of them are fairly serious. So let me discuss some of what I refer to as the "modal testing funnies" that I have observed over the past several decades of modal testing.

Impact testing and coherence - Many, many years ago (as well as just a few months ago) I observed a modal test where the engineers would only take one average for each measurement location. When asked why, they very clearly stated that since the coherence was one, why bother making any more measurements - how much better could they get ! I have seen many fall into this trap. The coherence is a function that can only be evaluated for averaged measurements. With only one average, there is no variation relative to the only measurement made. So, therefore the coherence can only be one - but is definitely not an indication that the measurement is acceptable. You can only use the coherence function to evaluate the variation on a set of averaged functions. Averaging is required!

Reference location at the node of a mode - In order to conduct a modal survey, the reference location (stationary response in a roving impact test and stationary input location for impact or shaker testing) must not be located at the node of a mode. The node point is a location of zero response. If there is no response, then how can a good FRF be obtained. I remember many years ago, a group was testing a large cantilevered type of structure and they had just procured some very expensive low frequency accelerometers. Concerned that the device might fall from the structure, the reference accelerometer was mounted at the base of the cantilevered structure - but of course there is no response to measure so the FRFs were very poor to say the least. Another test of a rib-panel cabinet structure was instrumented with all the measurement locations at the majority of the stiff rib intersections and no accelerometers on any of the panels portions of the structure. For this particular structure, it turned out that the modes of interest were mainly related to the panel responses. All the accelerometer locations were essentially at nodes of all the modes. Unfortunately, someone worked on this over several months and acquired many sets of useless data before asking for guidance and help. The measurements need to be at locations where there is response to measure. Avoid nodes of modes!

Mass loading effects - Now mass loading effects have been discussed in other articles. The mass effect of instrumentation can cause an effect on the measured FRFs and give a misrepresentation of the system natural frequencies. Care must be exercised to determine what mass loading effects, if any, exist. This may be a pronounced effect or relatively insignificant. But I have a mass loading story that is hard to beat. Back in the early 80s, I was involved in impedance testing of isolation components for submarine propulsion systems. New designs were being evaluated and impedance testing was being performed over a 5 KHz range with a new approach at the time called digital stepped sine; each test took approximately 3 hours to conduct. With many measurements for each configuration, many proposed prototypes to evaluate and only a dual channel analyzer, testing was performed 24-7 to complete the tight scheduled program. The configuration involved a set of 2 ton concrete blocks supported on air bags and separated by the isolation system. There was one particular co-op student (about 6'5" and about 350lb) who would run some of the third shift tests. Three months after the program ended, the analysts evaluating data called with some questions regarding several data sets that appeared to have a 400 lb difference in mass that appeared part way through the frequency range. Their comment sent a chill up my spine as I remembered coming into the shop assembly area where the tests were being conducted every morning and remembering seeing a pillow and blanket on the concrete blocks. After some lengthy discussion, it was determined that once the test was started, the co-op student would climb up onto the airbag supported concrete block to take a nap while the test was underway !!! You can imagine how hard it was to explain that unique testing problem. It turned out that since a very good logbook was kept for all the tests, it was easy to determine which tests the co-op was involved in and additional measurements were reviewed and some determined to be inappropriate for use. No one likes to keep an accurate logbook but this is one case where that information was invaluable. Now that is a mass loading effect that I don't think will be easy for anyone to top. Watch out for mass loading!

Double impact and force windows - Many times double impacts are unavoidable while performing an impact test. There have been several times where I have seen test engineers use the force window to eliminate the effects of the second impact of the double impact. Their thought process was that since I really didn't want to have a double impact, why not just zero out the effects of the second unwanted impact. At first thought, this might seem reasonable, but the reality is that the structure actually did see the double impact. Therefore, it is totally incorrect to apply the force window to try to analytically remove the effects of the second impact. The structure actually responds due to the actual double impact applied. Never try to remove the effects of a double impact through the use of the force window.

Averaging using a different point for each average - This is one you have to laugh at in complete disbelief. I witnessed a test eons ago, where the resulting mode shapes of a fairly simple structure appeared to be nothing more than shear gibberish. After checking some of the basic things that could be wrong, a lengthy discussion was held to determine why the coherence of the measurement could be so bad for a simple structure when 25 averages had been acquired. It turns out that there were 25 measurement points to be acquired. The test engineer took 25 averages for each measurement point for the modal test. Unfortunately, each of the individual measurements that made up the summation of all 25 measurements were obtained through an impact test where each individual point on the structure was impacted at a different location for the total 25 measurements. Basically, each averaged FRF came from the 25 averages from impacting ALL of the individual 25 points on the structure. This one averaged function was then labeled for one of the test structure measurement points. This process was repeated 25 times until all the measurement points were measured. Obviously, this is completely incorrect. An averaged FRF for a given point on the structure must come from a measured function where the SAME point is impacted for each of the averages. I still can't believe that one.

Coordinate systems and point/direction information - The proper identification of point and direction identification for a modal test is a fairly simple process - but sometimes errors result from incorrect specification of this information. A simple remedy is to clearly mark the coordinate system at the test setup. I usually put down tape on the floor with the x, y and z directions clearly labeled. Many people laugh behind my back at this routine but I never mess up point direction information for a modal test and many others often do. So I guess it is "he who laughs last, laughs best" and I am still laughing at some of the mishaps that I have seen. I remember one modal test of an engine block on its mount system. The test was used to basically identify the rigid body modes of the engine on the mount system - these are typically very low frequency modes. One day I received a phone call with a problem where the modal test revealed a flexible mode of the engine block in the 10 Hz frequency range. This was highly unlikely and I questioned the proper identification of the point and direction information for all of the measurement locations. The people at the test lab very abruptly stated that they were experienced modal test engineers and knew exactly how to identify this basic information. Not wanting to ruffle their feathers, I asked for the data to review. Upon close inspection of their data, it became very clear and blatantly obvious that one face of the engine block had all of the X direction transducers mislabeled 180 out of phase (basically they were pointing in the opposite direction as that specified in the modal software package). Once the phase was corrected for the measurement points of concern, the engine block rigid body modes appeared exactly as expected. Point and direction information is a fairly simple straightforward process - care needs to be exercised in this important step of the geometry generation.

Finite element models aren't always correct - Now that's a loaded statement. Many people have heard the statement that "Everyone believes the test except the test engineer and no one believes the model except the analyst." A large satellite structure was tested about ten years ago where a great deal of care was employed to accurately identify the shaker locations for a modal test with a very elaborate pre-test analysis using the finite element model. The model identified several shakers along the length of this long cantilevered structure attached to a huge seismic mass - but the two horizontal shakers were only set up in one of the directions perpendicular to the length of the cantilevered satellite structure. When questioned on the omission of exciters in the other perpendicular direction, the analysts firmly responded that there was no need for the exciters in the other horizontal direction since an extensive pre-test analysis was performed and ALL the modes of the structure would clearly be excited by the selected excitation directions. Well, it turned out that the model was not perfectly correct (and actually had many lumped mass elements incorrectly defined and located in the model). Therefore, the pre-test analysis was biased by the errors in the finite element model and therefore provided inaccurate information. The selection of reference locations is not an easy task. A finite element model, if available, is a great tool to assist in the selection of references. But care should be taken to not put too much faith and confidence in a model that has not been verified (which was actually the point of the test under way).

Bottom line - The bottom line for almost any modal test is that you need to carefully think about each step of the measurement process to assure that correct FRFs are obtained . The worst situation occurs when people stop thinking about what they are trying to do. I get upset when I walk in to a lab and see measurements being made with no understanding of what is being measured. Many times the response of the concerned people is that "this is the way we have always done it and it must be right because we have been doing it this way for years". It is all right to take measurements following a set procedure but it is imperative that everyone understands the logic and reasoning behind the approach and methodology used for the acquisition of FRF data. The first thing that should always be done is ***question assumptions*** to assure that everyone knows why things are done a certain way. The next thing I always say is that ***thinking is not optional!*** This is not push button technology like a hamburger joint where the choices are simple - burger, fries, soda, $4.52 please. Modal testing has come a long way in the past 25 years but we are still not to the fully automated modal test just yet.

I hope some of these stories have brought a smile to your face but just make sure you don't make the same mistakes! If you have any more questions on modal analysis, just ask me.