MODAL SPACE - IN OUR OWN LITTLE WORLD

by Pete Avitabile

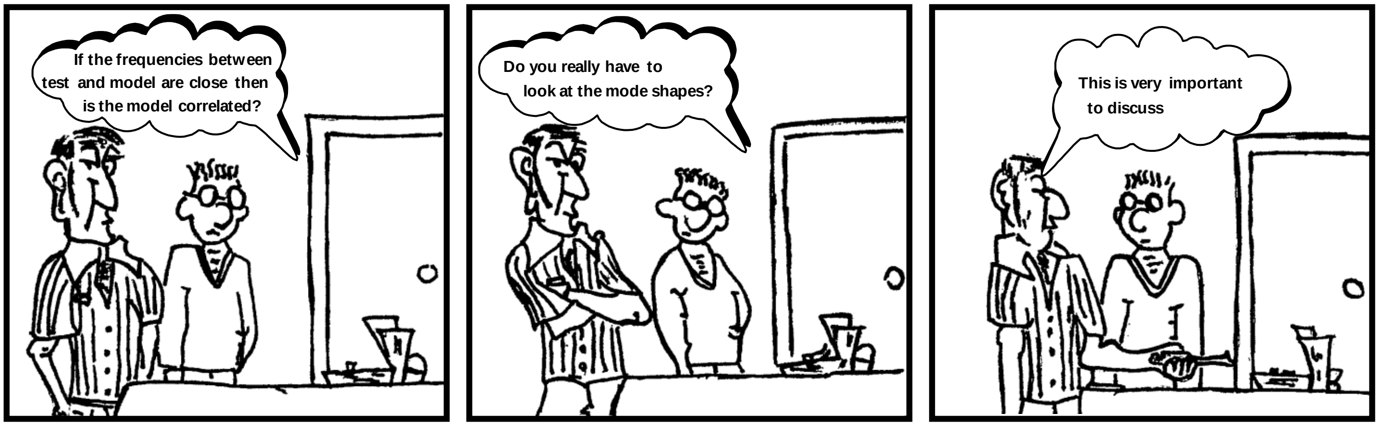

Illustration by Mike Avitabile

If the frequencies between test and model are close, then is the model correlated?
Do you really have to look at mode shapes? This is very important to discuss.

So this is yet another area where people often get confused. So many times people develop finite element models and there is a desire to make sure that the model is reasonable. Often times experimental modal tests are performed specifically for this sole purpose – to provide a sanity check for the model.

The finite element model is developed from many different assumptions and there are many areas where there is question as to:

- how the structure was modeled
- what material properties were used
- how the joints and connections were modeled

… and the list goes on and on.

This is because the finite element model is an approximation and it is a modeling tool that we use to assure that a design is reasonable for the intended use in its particular application. The model contains hundreds of approximations all of which may be reasonable for most designs. Fortunately, in design, we build in factors of safety and stress limits and other criteria to compensate for that which we don't know or understand.

Many times in the finite element model there are "penalty factors" or "knock-down factors" that are applied to the model because we just are not sure that we believe the properties that we use for the model possibly due to the manufacturing process used or because of fabrication techniques that may impose loads and degrade the general properties of the structure, etc.

The finite element models are approximations. We use the models to build in a "comfort factor" in the systems we design and build to have a greater confidence in our design. But the bottom line is that the finite element models we build are not perfect by any means. They are hopefully good approximations of the systems we try to dynamically characterize but … often times the approximations are forgotten in the development of the model.

For instance, everyone builds models that are very complicated and at times the complication is where the focus of concern may be directed. But many times simple questions as to what is the Young's Modulus or density of the material will raise an eyebrow as a possible source or error. Yet many times no one ever weighs the test article to see if the model weight and actual part weight are the same. And Young's Modulus is always just accepted as the published value with no thought of the variance that might be expected and how it should be checked.

And often times the CAD model is used for the model geometry generation without any real regard for what the actual geometry might be and how it may change the actual frequencies and mode shapes. One very important case is the flatness of panels that are included in a finite element model. The model may have the panel modeled as flat but the actual warpage of the plate may have a strong effect on the overall frequency prediction. Figure 1 shows some scans on panels that were stated to be flat and modeled as such in the model, but these deviations played a very important part of the frequency and shape determination.

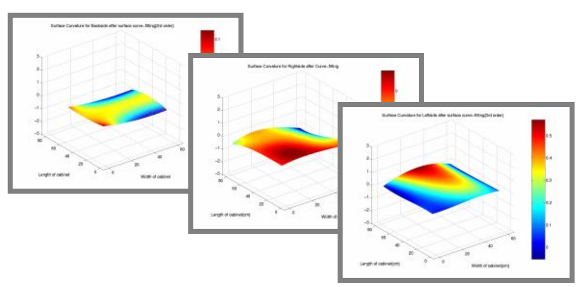

Figure 1: Distorted Geometry of "Assumed" Flat Panels

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In this particular case, the frequencies of the model matched many of the tested frequencies but the shapes showed essentially no correlation at all – so just matching the frequencies does not necessarily mean that the model is OK.

One particular difficulty that always causes problems is when the experimental modal test is performed with a clamped or built in condition. Where the finite element model can easily predict a built in or clamped condition, it is very hard to accomplish this in an experimental modal test set up – but people try to do tests this way all the time.

One case involved a composite plate that was developed with some new fiber and the characteristics for the composite plate model were being questioned. The plate was set up in a fixture to try to achieve a built in condition even though it was clearly known that the boundary condition may be difficult to achieve.

Unfortunately, the analytical group assured everyone that the fixture was more than adequate. And they clearly stated that it was "rigid", "stiff" and "more that adequate to simulate a built in condition for test".

Now the only thing that can be said here in terms of the test is that "It is what it is" and whatever is measured will identify the reality of the test set up. The first several modes of the composite plate were measured and a correlation study with the finite element model was performed. However, remember that the original finite element model fiber characteristics were not clearly known and the purpose of the test was to help define the fiber characteristics. Of course, the first correlation performed showed significant differences between the test and the model. This was anticipated to be largely due to the fiber unknowns. The frequencies showed quite a bit of difference but the shape correlation was considered reasonable as seen in Table 1. The three mode shape pairs are shown for reference in Figure 2.

Obviously, the model had some fiber characteristics that did not represent the true stiffness of the fiber in the composite arrangement. So with some minor tweaking of the fiber characteristics, the model was adjusted and the resulting frequencies were shown to be greatly improved. The model frequencies were then identified and were shown to be much improved as seen in Table 2.

But if you look at Table 2 you will notice that the MAC values are not shown. Due to time and budget constraints, no additional correlation studies were performed with the "adjusted" finite element model. Everyone felt that because the frequency comparison was greatly improved that there was no need to further validate the model – the frequencies are close so "end of story" so to speak.

Table 1: Correlation of Composite Plate Model and Test Data

	FEA (Hz)	EMA (Hz)	%Diff	MAC(%)
1	81.3	117.4	30.8	99.5
2	165.7	213.9	22.5	89.9
3	165.7	232.8	28.8	80.6

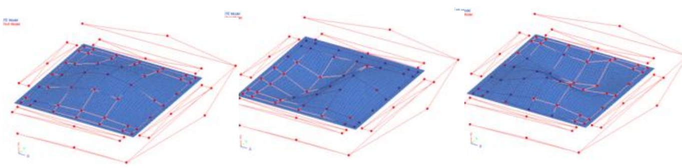

Figure 2: First Set of Correlated Mode Pairs

Table 2: Correlation of "Adjusted" Composite Plate Model and Test

	FEA (Hz)	EMA (Hz)	%Diff
1	113.7	117.4	3.1
2	233.7	213.9	9.2
3	233.7	232.8	0.4

But some time later several additional correlations were performed and as it turned out, the shape correlation had degraded significantly from the original correlation identified with MAC values for mode 2 and 3 much lower than before. While the frequencies appeared to be very close, everyone was happy to use the updated properties of the adjusted model. As it turned out there was significant effect of the boundary condition of the so-called built in or clamped condition. The frequencies had indeed gotten closer to the test frequencies but the fiber parameters of the model that were adjusted had a significant effect on the shapes of the first three modes – but that was never checked as part of the adjustment of the model. In fact, the boundary condition of the fixture was not as stiff as anticipated by the analyst and this had a big effect on the shape correlation.

So the bottom line is that the correlation clearly needs to compare frequencies and mode shapes. If only the frequencies are considered then the model can be adjusted (or maybe distorted) in just about any way to achieve "matched" frequencies. It is critically important that the shapes be evaluated as part of the correlation process to further justify and substantiate the correlation of the model to the test data.

There have been numerous instances to substantiate this and it is always recommended that the correlation of the model to the test include frequency comparison as well as shape comparison. The MAC is a first step to the shape correlation process but orthogonality checks are also needed for the validation of the model. (Some concerns of using only MAC as a vector correlation tool will be discussed in a future article.) If you have any other questions about modal analysis, just ask me.

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