## MODAL SPACE - IN OUR OWN LITTLE WORLD

*by Pete Avitabile*

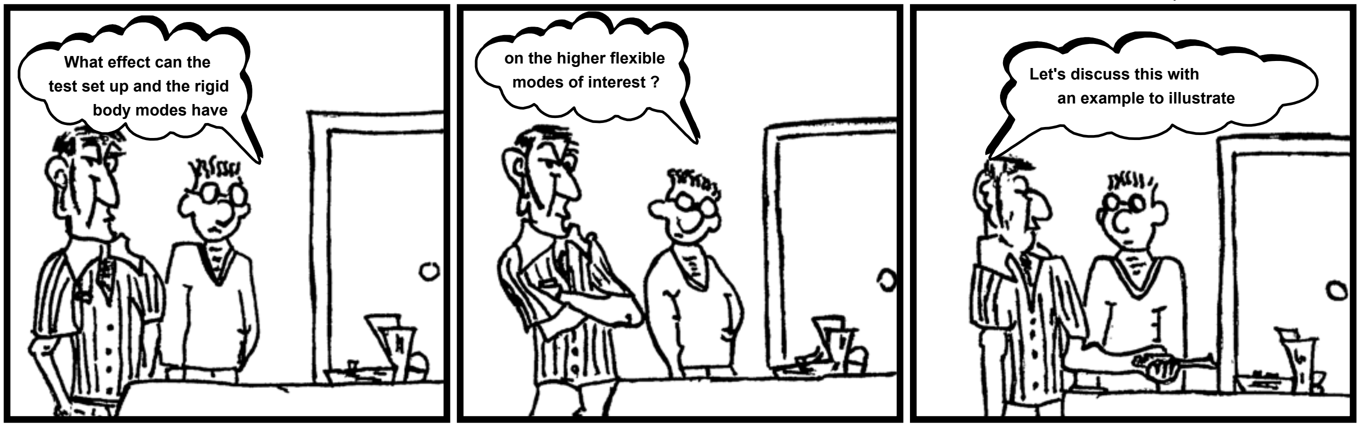


*Illustration by Mike Avitabile*

What effect can the test set up and rigid body modes have on the higher flexible modes of interest?
Let's discuss this with an example to illustrate.

This particular question comes up very often. In this particular case, the question was posed relative to ground vibration testing of an aircraft. The concern lies with the fact that if a different support configuration is used, how or will this effect the measured flexible modes of the system.

Now there are some very important questions to be answered here. All of them may be more than can be answered in one article but at least some concepts can be presented and some possible ways to better understand the problem can be presented.

In order to do this, I want to show some data that was recently collected in the lab for some composite plate specimens that were subjected to impact testing. The main purpose of the testing was to determine the damping of the composite material using a newer material formulation and compare these results to commercially available composite resins that are typically used.

One of the first things that was done was to subject the first prototype plate to a number of different proposed test set up configurations to determine if the test setup would have a significant effect on the results obtained. Since the plates were of a very lightweight construction, many different set up configurations were explored. Only four different configurations will be shown here to illustrate some of the differences that could possibly result. The composite plate was supported on a very soft elastic system and subject to impact testing using the multiple reference impact technique using three reference accelerometers. The impact test was conducted with the four different support configurations as shown in Figure 1 along with a photo of one of the test set ups. A typical frequency response function measured for one of the configurations is shown in Figure 2 (just for reference).

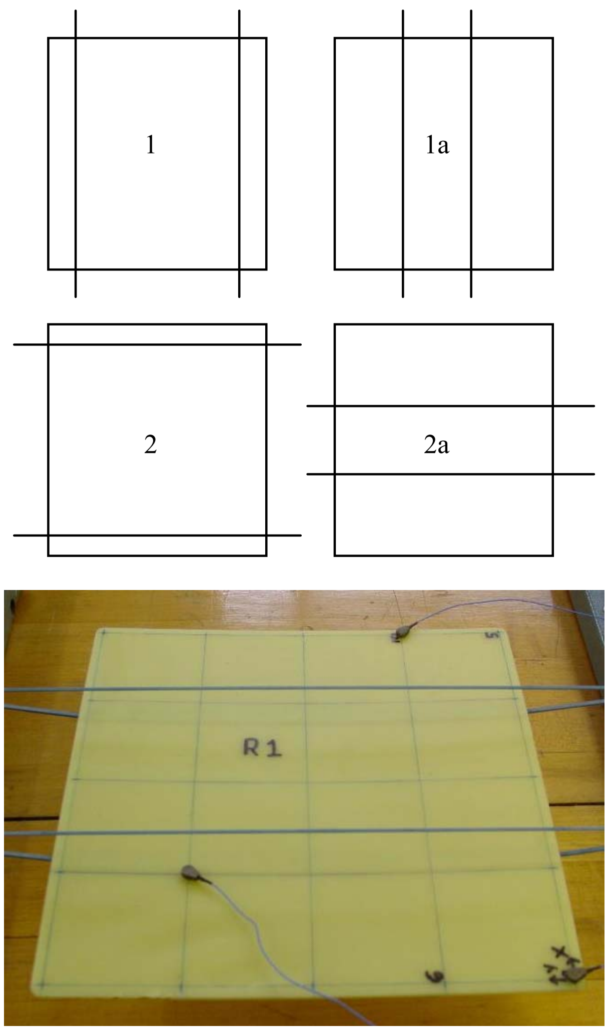


Figure 1 – Schematic of Four Different Test Support Configurations for One Composite Plate Sample

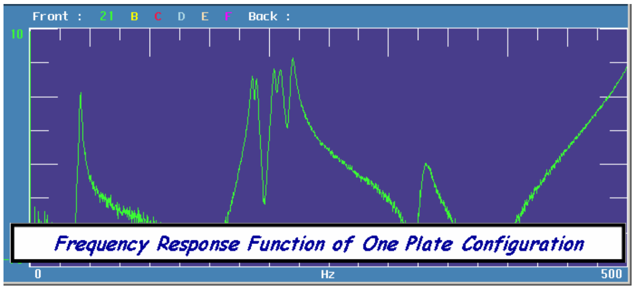


Figure 2 – Typical FRF Measured on Composite Plate

The data was reduced using normal modal extraction procedures and the results for the first four modes are shown in the following tables. The results all seem to be fairly consistent with the exception of the first mode of the structure. There is a definite difference between the different set up configurations. The frequency for most modes varies less than 1% except for the first mode which shows up to 5% variation on frequency results. (Now we can argue about fiber orientation and other factors but the bottom line is that there are differences.)

Test 1 Results (Outboard Supports)

| Mode | Frequency (Hz) | Damping (%) |
|---|---|---|
| 1 | 43.89 | 2.15 |
| 2 | 188.48 | 0.92 |
| 3 | 203.24 | 0.71 |
| 4 | 207.88 | 1.03 |

Test 1a Results (Inboard Supports)

| Mode | Frequency (Hz) | Damping (%) |
|---|---|---|
| 1 | 42.03 | 2.33 |
| 2 | 188.02 | 0.91 |
| 3 | 204.00 | 0.81 |
| 4 | 209.72 | 1.09 |

Test 2 Results (Outboard Supports Rotated 90 deg)

| Mode | Frequency (Hz) | Damping (%) |
|---|---|---|
| 1 | 43.97 | 2.19 |
| 2 | 188.51 | 0.91 |
| 3 | 203.01 | 0.75 |
| 4 | 209.73 | 1.05 |

Test 2a Results (Inboard Supports Rotated 90 deg)

| Mode | Frequency (Hz) | Damping (%) |
|---|---|---|
| 1 | 42.11 | 2.32 |
| 2 | 188.47 | 0.92 |
| 3 | 203.92 | 0.82 |
| 4 | 209.88 | 1.07 |

It is important to note that the rigid body modes are significantly lower than the first flexible mode of the system. (It is difficult to see from the measurement shown but the rigid body modes are close to 1 Hz.) That means that there is much more than a 10:1 ratio between the rigid body modes and first flexible mode of the system. But notice that the first flexible mode is definitely affected by the support configuration.

Everyone always says that as long as there is greater than a 10:1 ratio then there is no effect between the rigid body modes and the flexible modes of the system. But that really depends on what you agree is “close enough”. In this case, if you are willing to accept a 5% variation in frequency, then maybe we could agree that there is “essentially” no effect of the rigid body modes on the flexible modes of this system with the 40:1 ratio between the rigid body modes and flexible modes. But you need to check this and you need to have people agree that this is acceptable. It really depends on how accurate you need your data to be. This will always vary from case to case and industry to industry and test configuration to test configuration.

In the case of these composite plates, there were many modal tests performed and all the results were carefully compared. And not just frequency was compared. Mode shapes were also compared to determine the variance that might be observed from the sets of data collected. You need to check both frequency and mode shapes.

The data collected must be interrogated to determine how the frequencies and mode shapes will vary due to these different test configurations. Maybe there is very little difference in mode shape which may be the parameter of interest. Or maybe the frequency is a sensitive parameter for the design under evaluation. This really depends on the application at hand.

So what should you do? Well… if there is an analytical model available, then it is a very easy task to investigate the effects of different boundary condition on both the frequencies and mode shapes. Each configuration can be easily evaluated using correlation tools to determine the effect on the reported frequencies and mode shapes using vector correlation tools commonly available. This can be done prior to running the actual test to determine what effects, if any, might be observed. In this way, some evaluation can be made as to the expected variation in modal characteristics. Analyses can be performed to determine how these changes in characteristics may effect the final system response. If the effects are significant, then the effects of the test support condition need to be carefully evaluated. But if the results of the system response are not significantly different then the effects of the test support condition can be considered to be not as critical. But someone needs to make this evaluation. Rules of Thumb that are used are exactly that – they must be evaluated in more depth and should not be blindly followed. And remember that a change in the stiffness of the test support ***must*** have an effect on all the frequencies. If you add stiffness the frequencies must shift upwards – the question is how much do the frequencies shift and is it of importance or is it measurable.

I hope that this little discussion has shed some light on the effects of test set up on the frequencies and mode shapes. You need to evaluate this carefully. If you have any more questions on modal analysis, just ask me