Illustration by Mike Avitabile

We updated a composite plate model but the properties seem to not be physical.
Can the model be used for response studies? Let's take a look at this to understand this problem.

So this is an area where people often get confused. We make analytical models as an approximation of the characteristics of a system. Many times we use modeling approximations or equivalencies that help to obtain the right overall characteristic for the model. But it doesn't necessarily mean that the model portrays the actual physical property as we may expect to see it as if we were to get it from a material properties table.

Actually I have a very good case that may be a good one to present related to the modeling of a composite plate that was modeled with some radically different modeling strategies. I really don't need to go into all the details of the modeling philosophy and strategy deployed but I will only concentrate on the confusion of the material properties that resulted from the model updating performed.

A finite element model of a wind turbine composite section was developed. The physical structure had a balsa core and a 5 ply resin fiber layer (0-90° warp-weft architecture) on each side of the balsa. The finite element model used a unique modeling strategy to capture the resin/fiber composite with a plate and beam formulation to capture the shear and bending characteristics of the fiber embedded in the resin which is modeled as a plate. This modeling scenario had been used in the past but a prototype was also fabricated to perform some modal tests to validate the model. The testing was performed on a 3 ft x 3ft plate in a free-free condition as well as in 4 separate configurations with each side of the plate clamped to a 500 lb block to form a constrained end condition. The material properties were provided from the materials group and were identified as being accurate for the identification of its characteristics. The finite element model was developed with these properties identified as supplied by the materials group. A free-free modal test was performed and used to study the model adequacy.

The free-frre correlation of the first dozen modes produced very good MAC values but the frequency had a very consistent shift in frequency for all the modes of the system. A model updating study produced a very significant change in the balsa material properties to cause the frequency difference to be minimized; the basic premise was that the resin and fiber material properties that were provided were correct. But the balsa which is geometrically located at the neutral axis of the plate needed to have a tremendous change in stiffness in order to accomplish this shift in frequency; the updated balsa properties for Young's Moduls essentially needed to be that of steel. While this may seem unrealistic from a practical standpoint, the reality is that the finite element approximation made with the composite materials used required this in order to achieve the proper stiffness to represent the modal characteristics properly. The results of the original free-free correlation and the updated free-free correlation is shown in Table 1.

In order to confirm that the model was a reasonable approximation of the system even with the unrealistic balsa properties identified, the plate was tested in 4 perturbed conditions where it was clamped on each of the 4 sides of the plate. The finite element model *with the updated properties* was correlated to each of these configurations and produced comparable results to the free-free update models; only limited results are shown to keep the article brief. Table 2 shows the results of the correlation of the finite element model *with the updated properties* for the stiffer and softer direction of the composite plate clamped to a 500 lb anchor in the lab; the model was made with the anchor included to best represent the clamped arrangement. Clearly, the update parameters are suitable to predict a significant change in the boundary conditions made to the free-free composite plate structure.

Table 1: Correlation of Free-Free Composite Plate Before Model Updating (left) and Correlation After Model Updating (right)

#	FEA Hz	EMA Hz	MAC
1	22.13	49.90	99.9
2	48.82	84.34	99.3
3	65.20	129.94	99.7
4	101.74	138.49	98.7
5	109.56	166.55	99.8
6	128.46	230.26	99.6
7	135.95	252.14	99.3
8	142.08	267.53	99.3
9	194.58	386.93	96.6
10	204.93	359.29	97.6

#	FEA Hz	EMA Hz	MAC
1	49.64	49.90	100
2	87.19	84.34	99.8
3	131.23	129.94	99.9
4	134.28	138.49	99.6
5	163.65	166.55	99.9
6	229.83	230.26	99.8
7	249.63	252.11	99.8
8	266.60	267.53	99.8
9	355.74	359.29	99.5
10	381.52	382.79	97.1

Table 2: Correlation of the Update Finite Element Model to Two Different Tests with Significantly Perturbed Boundary Conditions with the plate Clamped on One Edge

#	FEA Hz	EMA Hz	MAC
1	20.06	19.19	99.1
2	32.86	31.98	99.1
3	99.69	98.19	98.9
4	124.61	127.25	97.8
5	133.35	135.64	98.2
6	199.99	204.16	99.4
7	241.21	241.29	99.2
8	281.52	298.25	97.5
9	307.01	317.41	94.4
10	355.27	354.81	98.1

#	FEA Hz	EMA Hz	MAC
1	13.93	12.68	99.2
2	30.20	29.54	99.6
3	82.12	84.58	94.7
4	108.58	109.27	99.6
5	143.58	147.37	99.8
6	203.78	208.57	99.0
7	224.81	229.96	97.6
8	236.02	240.43	99.1
9	329.40	338.66	99.0
10	360.70	363.54	98.0

So many people might ask, how can you have such different material properties for the balsa approaching those of steel and expect the model to be reasonable. Well that is an excellent question and is one that needs to be discussed. I have a great example that I think you will very quickly accept.

We know that an I-beam gets its significant Area Moment of Inertia from the flanges being offset from the neutral axis. But I could reduce that down to an equivalent rectangular cross section to give me the same effective stiffness as seen in the upper portion of Figure 1. I have certainly captured the stiffness properly to get the right deflection of the system. But if you looked at the cross section you would say that it doesn't really look like an I beam.

Now in the composite plate model where we changed the balsa property, the effective composite materials we used did not really represent the true stiffness of the material. Because the composite fibers are outboard of the neutral axis of the balsa, their effect in defining the stiffness of the system is critical. In the first model we used "whimpy" material properties so to speak. So the only way that the model could reflect the difference in stiffness is by adjusting the Young's Modulus of the only element left in the model that could change – that is the balsa. So the balsa had to be very stiff – almost on steroids so to speak. While we may not believe that modulus from a physical standpoint, as far as the model was concerned, the balsa needed to be that stiff. If you look at the overall EI of the balsa and resin and fibers *as a complete unit*, then the overall stiffness is represented correctly as well as the mass distributed correctly and we predicted well over a dozen modes correctly – and in 2 different perturbed boundary conditions as well.

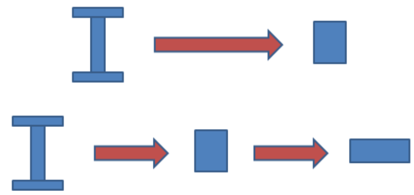

Figure 1: Schematic – Equivalent Section Properties

And let me take it one step further and look at the lower sketch in Figure 1. Let's say for some reason we couldn't let the rectangular approximation be as high as it is and we needed to make it half as thick. In order to do that I would need to change the stiffness somehow because the I about the weaker axis would not be as stiff as the thicker section. Because the I has a t^3 term, we would have to increase the effective stiffness of that thinner section by adjusting the EI term to account for the change. So the E would need to be adjusted by 2^3 to make the overall cross section have the same effective stiffness. But the real E of the material would not be that value –the model would need to adjust the material to compensate for the change in physical dimension.

So the bottom line here is that we take everything into consideration in terms of the overall mass and stiffness distributions to cause the system to have the right overall effective representations so that the ***response*** is measured properly and the structure has the right overall weight as well as the right stiffness such that if you put a static force on it you get the right displacement.

And as a side note, eventually the material properties were re-evaluated with updated material testing methodologies and correlation to the finite element model was significantly improved with very acceptable frequency and shape correlations. Now the material properties of all materials are more in line with what we may have expected. But the bottom line is that any of the updated models could have been used for a proper estimation of system characteristics when only considering response of the system. If you have any other questions about modal analysis, just ask me.