EDITORIAL

The History of Finite Element Analysis from the Viewpoint of One User

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My association with *Sound and Vibration* is decades old mainly because of my prior association with fellow editor George Fox Lang. We met at the GM Proving Grounds where I was a co-op student while George was already a seasoned engineer. George eventually went off into the world of testing equipment while I developed an interest in analysis during grad school.

FEA, as Finite Element Analysis is acronymed, was in its infancy in 1971 as I labored for my master's degree. I was very fortunate to take a course in the subject from a visiting professor who had recently been at Boeing. FEA use was extremely limited but Boeing had done a significant project – the thermal-stress analysis of the Boeing 707 engine supports. What was unique was that the structure was statically indeterminate. Airplane designers knew that an indeterminate structure could be stronger than the determinate structures they had always used. But, if you couldn't analyze it, you didn't really know how strong it was.

Let me digress slightly here. A statically determinate structure has only one load path and the basic forces and moments can be calculated manually. In two dimensions, a triangle with pin joints is statically determinate. Add a 4th member from one of the vertices to a point on the opposite leg and you have an indeterminate structure. It's probably stronger but harder to calculate how good it is. FEA makes this calculation quite easy. I see all of you testing folks out there yelling and waving. Why not just test it and you'd know? Well, if there were only a few possible loadings, that would be the right thing to do unless you hadn't built one yet, or the cost and time to build one was prohibitive. In that case, it might be good to analyze it first so you are pretty confident it will work and you will test it later. Plus, a test only tells you the load where failure occurred. There might be other locations that will fail at 1% more load. Without a lot of strain gages, it might take many tests to produce an optimum design. It would be easy to get embroiled in whether to test or analyze but there is no universal answer. An analyst can define a problem that can only be analyzed while a testing engineer can define a problem that is too hard to analyze.

Anyway, Boeing did choose to analyze the engine support for the 707. FEA and the computers of the day were somewhat primitive. Coding of the model was done by a team of many engineers. Getting the model right was really hard with no interactive graphics. You were really lucky to have a pen plotter and hidden line algorithms were years in the future. Eventually a run was made and run time took many days. Model size was very limited mainly because of tiny amounts of available memory and disk space by today's standards. Temporary files were often written to magnetic tapes. If you needed 5 temporary files, you would use 5 tape drives. Output was pages of printout. Pages is a poor description. In fact, the output was delivered by a tractor-trailer. The many boxes of output were distributed to the team of engineers who then tried to figure out what it all meant. This is a similar story to the one told by my grandparents where they hiked six miles through the woods, carrying firewood, to get to school.

A decade ago, I used to write articles and do presentations at conferences telling war stories similar to the above paragraphs but have done very little of it since. I thought that FEA was considered to be a new technology and was not fully trusted back then. Now, it is mainstream technology and the need to justify it has faded. But still, I find it interesting to look back, particularly as I ponder the end of my own career. I'll get to the reasons later.

After a few years in grad school, I got tired of formal education and took a job in the Naval Nuclear industry. This was fortuitous at least from the perspective of becoming an FEA specialist although I didn't realize it when I took the job. The year was 1973. Computers had advanced some. There were some very primitive commercial FE codes around but I used an in-house program. Getting good answers was really hard work, but using it would allow you to do more complex problems than by hand. I was immediately considered to be experienced as I had taken a college course in the subject. Minimal experience is valuable when everyone else has none. Considering how difficult, and therefore expensive, FEA was back then, its use was limited. Basically, it had to be something you couldn't analyze by hand accurately and was too expensive to test. Nuclear reactors and airplanes are two applications that come to mind. As the programs became more capable and easier to use and computers became faster and cheaper, use would spread.

Of course this is exactly what happened. We were stuck on mainframes for some years but, as more companies acquired them, their cost dropped and their speed improved. We even got some interactive graphics although the only color would be green for awhile and modem speeds were pathetic. But it was still better than punched card input and printed output. I won't cover precise details here but we got departmental minicomputers, much faster and color graphics, Unix workstations and finally PCs on the hardware side. On the software side, we got commercial FE codes each with dozens of developers and they competed for users. The marginal ones died or were absorbed, but the strong ones became significant public companies. There are now a number of FE companies with revenues over $100 million. This trend has covered the last 30 years. I purposely omitted precise details. As a brief example of how things have improved, I recall the first 3D shell model I did back in the 70s. It took a good month of hard work. Today, a much better model could be done in less than an hour. There was some 3D solid geometry we had to leave out. This could now be included and the time would still be a day or so. And the results would be better and produced as color contour plots.

It is now near the end of 2002. We are in an economic slump. From here, in Silicon Valley, it looks more depressing than slumping, but economic trends are always magnified here. The FE companies are fewer due to acquisitions and many of them are now publicly traded. This is not a good thing as they now have shareholders who care little if at all for the technology and only care about increasing sales. And, they mean this quarter not next year. FEA used to be the domain of specialists but there aren't enough specialists to buy enough software so almost the entire FEA industry has shifted focus and created products whose only positive feature is ease of use. Accuracy of results and advanced capabilities are secondary considerations. The only real question for discussion is whether the product can be sold to designers who don't have the background, desire or patience to run a real FE program.

What has driven this change in direction is the need to increase sales to maintain stock prices and that can't be done selling to traditional analysts. During the time that FEA was developing, there was a larger economic development in mechanical engineering – the 3D CAD system. There are at least 10 times as many CAD users as FE analysts. These CAD users have 3D geometry and they would like to use it for analysis.

Never mind that the geometry may not be very precise or that the designer has little background in analysis. There are lots of these folks and selling a FE program to them is the way to make sales goals. Literally all FEA companies have taken this approach. It is possible for this to work well. It can also be a disaster. The main issue is whether the designer created a clean model or not. Any CAD system can create good or bad geometry. It is primar-ily the skill of the CAD operator that determines whether it can be used for analysis. It seems that most recent consulting projects start from CAD geometry. Use of CAD geometry within a company can be made to work but it takes some cooperation. When a company sends CAD data out for analysis, it is often the first time they have tried this and none of the bugs have been worked out. They read the technical journals that talk about reliable and seamless data transfer. If it didn't work 100% of the time, would the software vendors admit it? I have been caught in the middle of this too many times. The CAD model may be inappropriate for analysis but the designer isn't willing or able to fix it. If it won't transfer cleanly, then our software is bad or we just aren't skilled enough. I can't fix this problem but I can retire.

This editorial was prompted by the desire of S&V to expand its coverage of FEA. My inclusion as an editor was done years ago with the same goal but I can't say it has succeeded. Testing and FEA should be complementary disciplines as both tools may get the same result. Each has strengths and weaknesses. There is an increasing number of engineers who practice both disciplines but they are still few. Expanding *Sound & Vibration* to include more CAE (Computer Aided Engineering) sounds like a good idea. The testing folks get exposed to FEA and some FE analysts will see what testing is doing these days. More magazine circulation ought to be a good thing. Editorial content that reaches both disciplines is needed. Much of this will likely come from the software companies and that poses a significant danger. They may see this as a marketing opportunity. A technical publication should not be turned into an advertising journal for the CAE software suppliers.

Technical content is difficult to find. Even articles that appear to be technical at first glance, can reach a point where they claim how this or that wouldn't have been possible without this great new CAD system from . . . or the seamless CAD import software from . . ., etc. You get the idea. It'll be a struggle but also probably the right thing to do. The search for meaningful CAE articles is on. SV

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