all that noise

It can come from instruments and test designs and even geometry, and it can add considerable cost to computer analysis.

By Jack Thornton

Jack Thornton is a technology consultant and frequent contributor to *Mechanical Engineering*.

Noise is a fact of life. We hear it as wind, traffic, other creatures, sometimes the pulse in our own ears. We are also surrounded by electromagnetic noise—radio and TV signals (plus their own interference such as static and background "white" noise), signals from cell phones and Global Positioning Systems, and the 60 Hz signals in the wiring of every home, office, and engineering laboratory.

Noise is also the unwanted data that accompanies all but the simplest measurements. And according to experts in the field of digital simulation, noise in data can be costly, in terms of time, money, and error, when it gets into computer analysis of engineering designs.

According to George Laird, principal mechanical engineer at Predictive Engineering in Portland, Ore., "Engineers often think that experimental data, one of the major sources of noise, is 'gospel' and that FEA is suspect. In reality, experimental data is often suspect."

Noisy data can be fuzzy or scattered when plotted out.

Fuzziness is found in measurement readings from test instruments. Measured points lie along a trend line and noisiness is a function of the percentage of points lying off the trend line and how far off those points lie. When plotted out, signals with thousands of points in a data set, look like fuzzy fur. Eliminating fuzziness can mean examining every data set as well as any cleanup methods.

Scatter, or randomness, is usually associated with the measurement of physical properties of materials. Trend lines are less clear in data scatter than in fuzzy data. Scatter is typically a few dozen data points, and is resolved with sampling, filtering, and similar techniques. Again, data sets and cleanups must be examined.

Clutter, which is not always a matter of fuzziness or randomness, can have the same effects as noise. Clutter is found in CAD models imported into FEA. These files can contain duplicate and overlapping surfaces, call-outs, tags, and labels, as well as geometry too complicated for practical analysis. FEA practitioners say that getting rid of clutter means eyeballing and deleting individual details, thousands of them in extreme cases, until the model to be analyzed is sufficiently compact to fit the computer's calculating capacity.

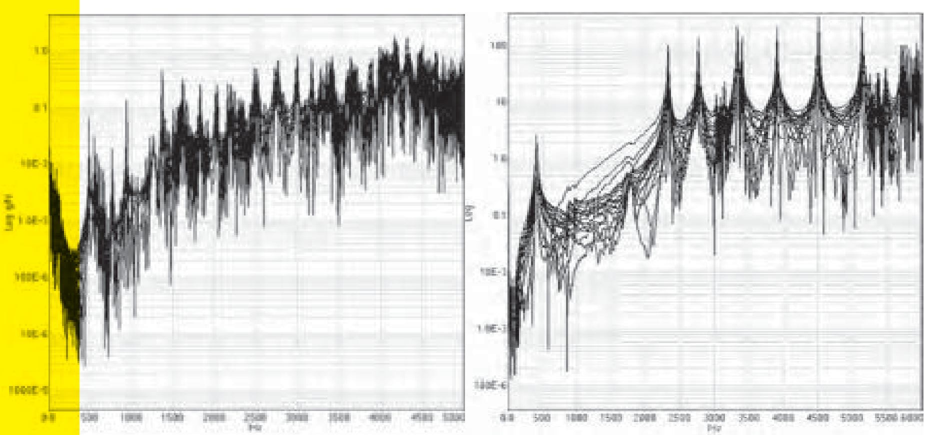
Noisy data can be cleaned up and used—even when the noise exceeds the signal, analysts say. Indeed, analysts insist that noise in any form rarely if ever gets into analysis itself, and thus noisy data rarely distorts FEA results. However, much time and money are spent upfront, before any significant analysis is undertaken, sifting out noise.

Of course, there are cases of "uncertain" data, with deeper problems, most of which trace back to human error in selecting, gathering, or formatting; to test equipment that is ill-suited or poorly calibrated, or to experimentalists lacking key skills or information. In FEA, noisy data is a subset of uncertain data.

Unless root causes are fixed, data of these sorts cannot be used. The analyst has to start over by searching out better information. Rigid budgets and deadlines compound the problems.

Alan McKim, vice president of customer service at SimuTech Group – Canada in Toronto, said, "One needs to relate the pretty pictures in the simulations back to the initial information. This is critical in identifying noisy data. The data may not initially appear noisy, but after the simulations are run and stress levels are, say, 10X the allowable, then questions are raised." SimuTech Group is an ANSYS reseller.

Finding and eliminating noise can make significant hits to engineering schedules, deadlines, and budgets. In extreme cases, data cleanup can devour half an FEA project's resources.



›Teasing usable data out of a noisy signal (left), reducing uncertainty to get usable data (right) with averaging. Data of this sort are typical of analyzing a loose connection within a structure or a sensor that itself has a problem.

SIMUTECH GROUP - CANADA

Peter Barrett, vice president of CAE Associates, noted that "costs associated with noisy data sets include wasted engineering time in creating an FEA with errors, wasted time in determining if the analysis has bad data, or fixing it, and drawing incorrect conclusions from a bad analysis." CAE Associates in Middlebury, Conn., is also an ANSYS reseller.

The costs of wasted time add up quickly at $50 an hour for a designer and $150 an hour or more per staff engineer. Rates for independent experts are two to three times higher. To this must be added the costs of engineering resources wasted, computer systems sidetracked, and deadlines missed.

Because of the extreme complexity of FEA calculations—hundreds of thousands of partial differential equations solved simultaneously—small variations in input data, if they are not corrected, are multiplied over and over, and magnified in the outputs. This would render analysis results useless.

One source of unnecessary noise, analysts say, is misunderstandings in engineering—especially loads and how they are to be applied. In the complex world of FEA, misunderstandings can easily arise, often from failures of communication among design engineers, analysts, and the experimentalists who run physical-testing labs.

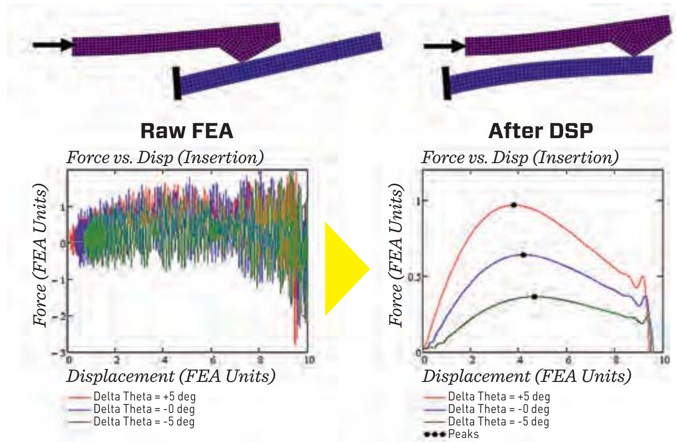
"This is why it is critical to identify whether data supplied by customers is or could be noisy," said Vernon McKenzie, a director at EnDuraSim Pty. in Australia. "We encounter noisy data, as an example, wherever loads are assumed rather than known. That means any measured loads need to be investigated to verify that the data is believable. A second investigation is needed to determine whether the data is representative of intended usage." EnDuraSim, based in Beecroft, near Sydney, resells Femap and NX-Nastran.

Failure to communicate is sometimes a lingering disconnect between those working on different parts of a project. According to Ted Diehl, president of Bodie Technology in

Unionville, Pa., "FEA users and experimentalists in many companies still throw results over the wall at each other, never looking closely at what the other side actually did and how they collected and manipulated the data." Bodie develops training courses and digital signal processing tools to clean up noisy data, mostly in FEA outputs.

Among the most challenging sources of noisy FEA inputs are the strain gauges, extensometers, pressure transducers, accelerometers, displacement meters, and so on used in tests and experiments. These instruments are attached at strategic points to material samples and prototypes. The readings become the loads, locations, and vectors in FEA. The readings also are used to validate analyses.

According to Bjarni Tryggvason, president of QDAC Systems in Mississauga, Ontario, "Product designers and other engineers generally do not know they are providing FEA with noisy data. They think noisy data is the way things are, since they have typically not seen really clean data." This is more failure of understanding, however, than failure to communicate. QDAC develops signal-processing tools for data conditioning and analysis.



Cleaning up noisy data in a quasi-static sliding snap fit, represented by red and blue objects (top). Noisy data (left) is the actual output of explicit-dynamic simulation. Low-pass digital signal processing avoids aliasing for smooth, accurate results.

BODIE TECHNOLOGY INC.

Part of the noise problem is test setups that don't match the assumptions in the analysis. "Often subtle variations in test setups and/or part variability will change the complex relationships in the physics of the analysis," said Dieter Featherman, program manager at Altair ProductDesign, a unit of Altair Engineering Inc. in Troy, Mich. "Noisy or inaccurate input to an analysis can potentially drive engineering and design decisions in the wrong direction," he added. "If so, consequences can be tremendous."

Closely related to mismatched test assumptions is part-to-part variations among test samples or prototypes. "These variations will produce additional noise in the measurements, which leads to challenges in correlating with the analysis, " Featherman said. "These variations can undermine the accuracy of the analysis, and its credibility."

Troublesome numbers often underscore the need to rethink the problem. Ken Perry, principal of EchoBio, said, "If you can't clean up the experiment enough to make your data sets useful, then design a better experiment." Working from Bainbridge Island, Wash., Perry focuses on design and analysis of arterial stents and related medical and surgical products.

Analysts note that several challenging trends in FEA complexity are expanding the dimensions of noisy data.

Analyses of assemblies—complete motors and aircraft wings, for example—may have dozens

Correlating experimental test data from measured durability loads in an four-post test rig with an FEA simulation of a vehicle's left and right front frame mounts, coil springs and bushings. Noise creeps into FEA when correlations such as this one are not done correctly.

ALTAIR ENGINEERING

Cures ... and Prevention

Experts in computer simulation and analysis offer many recommendations for dealing with noise.

One sure way to keep noise out is to examine and clean up raw data sets from measurements and experiments before that information finds its way into the analysis, they say. The widely used cleanup techniques and tools—smoothing, sampling, filtering, averaging, curve fitting, etc.—are available in today's FEA packages. These tools are also in FEA front-end geometry packages known as meshers and in general-purpose data handling preprocessors for computer-aided engineering.

More effective than cleanup is finding the root causes of noise, analysts say, and they have offered a number of suggestions for dealing with the issue:

- Understand what tests can and cannot reveal about properties of materials—especially complex materials like composites.
- Avoid the temptation to dismiss data scatter and randomness as mere noise; scatter is often statistically important, because it can reveal anisotropy in a material.
- Assume that data sets may contain errors, especially information provided by customers.
- Bear in mind that loads in experiments may have been applied in ways that differ from what would happen in the real world.
- Delve into iffy data sets from experiments. If necessary, ask that experiments be repeated and that instruments be rechecked for proper placement.
- Remember that instruments can be misread, may be out of calibration, and are subject to signal interference.

If these approaches aren't working, call in an expert. "It still takes a trained and vigilant engineer searching for problems to discover the noise in the data," said Dieter Featherman at Altair ProductDesign.

There is also an end-run for noisy data. This is the strategy of using worst-case loadings. "Design the analysis to withstand that worst case," advises Terry Bender, principal of Applycon in Hamel, Minn. "The design should then easily survive the lesser cases."

Verification & Validation Guide

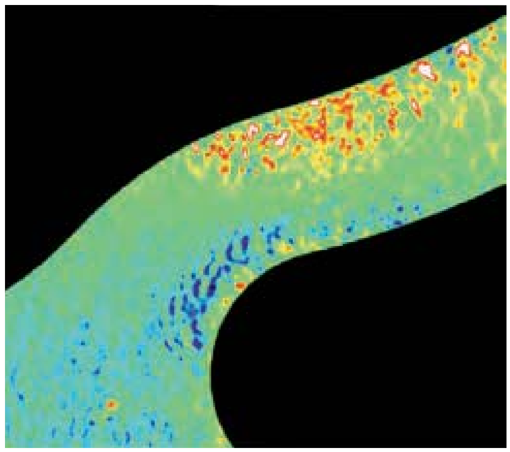
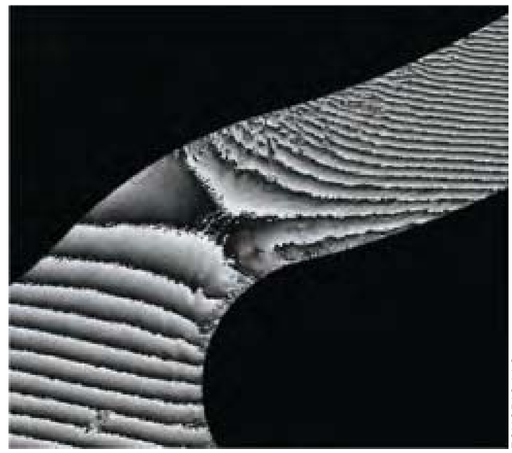
To help guide engineers through the FEA labyrinth, ASME has several V&V standards committees. The first document produced by these committees is V&V 10-2006 *Guide for Verification & Validation in Computational Solid Mechanics*, which spells out how the validation process is best applied to align finite element analyses and physical experiments.

V&V 10-2006, which is recognized by the American National Standards Institute, also discusses the use of uncertainty quantification as applied to both the FEA and physical results to establish confidence in the results—how well the results correlate with the real world. Verification, the other half of V&V, is about the mathematics, programming, and solving of partial differential equations, and refining the mesh to identify the discretization error.

"Essentially V&V is about providing evidence—including uncertainty in its many forms—that the numerical results are credible," said Len Schwer, recent past chair of the ASME's V&V 10 committee. He owns Schwer Engineering and Consulting Services in Windsor, Calif.

of parts. As the number and complexity of objects in an analysis rise, so does the associated noise and clutter, analysts note. And so does the time and effort to identify and correct for the interference.

The variety of materials undergoing computer analysis is increasing to include plastics, rubber, wood, composites, masonry, and even the ground beneath our feet. Measuring these materials inevitably means scatter in the data, far more so than in the metals and alloys with which FEA dealt during its formative years. Analysts also deal routinely with assemblies or systems that contain parts made of dissimilar materials.

ECHOBIO LLC.

At left, noise (all colors but green) in fatigue-loading measurements of a nitinol structural element in a heart valve. Minimal smoothing or filtering has been done. Piece shown is a fraction of a millimeter in diameter. At right, raw data from moiré interferometry time-data studies of the heart valve component. After smoothing with phase-shifting, least-squares solutions for noise generate correct displacement measurements. This type of noise clean-up can be automated.

Complex materials and models sometimes call for experiments "that often cannot be performed easily in real life," said Hubert Lobo, president of DatapointLabs in Ithaca, N.Y. "Attempts to do these experiments may result in material data that contains experimental artifacts such as noise and oscillation in the stress-strain data."

Most FEA programs "have great difficulty dealing with this variability, noise, and oscillation," Lobo said. "While partial solutions exist, careful consideration must be given to the selection of material properties to calibrate even simple parameters like modulus, yield strength, and failure strain." DatapointLabs is a widely known materials testing organization for FEA.

The opportunities for noise to get into input data sets is probably greatest in structured composites—highly engineered matrices of carbon fibers in plastic resins that are widely used in aerospace. "The biggest challenges in dealing with structured composites are how to measure their mechanical characteristics and how those measurements are calibrated," said Olivier Guillermin, director of product and market strategy at Vistagy Inc. in Waltham, Mass.

Vistagy's FEA software analyzes both the composite part and the way it is manufactured. Guillermin noted that Vistagy "deals with varying materials, differing thicknesses and off-specification orientations of the plies," none of which causes serious problems in analyzing simpler materials. (Plies are the woven layers of carbon fibers that give composites their great stiffness.)

Alan McKim at SimuTech Group – Canada talks about noise this way: "A piano or violin solo can be beautiful music. However, if you put a number of musicians together in a room, the first time they perform together, there will be a lot of noise before they become a symphony." So too in FEA.

"When you get a group of musicians together, the conductor orchestrates the individual performances," McKim said. "To address noise going into any analysis, thorough review of the data and coordination of all the parts of the analysis are critical."

In minimizing FEA input noise, knowledgeable engineers take on a role not much different from that of a symphony conductor. ■

To Read More

To further understand how to deal with noise in analysis, Ken Perry of EchoBio recommends:

Numerical Methods for Experimental Mechanics by Donald G. Berghaus (Springer, 2001).

Random Data: Analysis and Measurement Procedures by Julius S. Bendat and Allan G. Piersol (Wiley, 2000).