From eardrums to electromagnetics, researcher hears the problems

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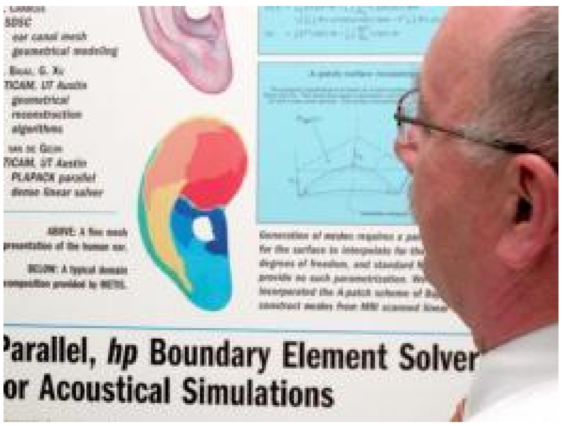

A good tool is both robust and accurate; it doesn't break down easily, or give faulty readings or results. This standard applies to everything from a bathroom scale, or vending machine to a sniper rifle. It also rings true for computer code. Industry and agencies use computer code to design products and test research in the digital realm. It cuts down and time and cost, and can allow a design to be tested in a variety of conditions. Teams of scientists and engineers at companies are dedicated to implementing codes that work efficiently and represent reality—codes that are robust and accurate. But sometimes, they get stuck.

"They modify existing commercial software or work with vendors, or work with house code and tools. It's when all this fails that they pick up a phone and call us," says Leszek Demkowicz, the leader of the ICES Electromagnetics and Acoustics Group.

Basic research, real problems

Demkowicz has gotten quite a few phone calls over the years.

Oil companies have called him about modeling streamers, three-mile long tools that map what's under the sea floor while skimming along the ocean surface. And a phone call from a friend with a deaf daughter started his research on the acoustics of the human head.

The problems that come across his desk are diverse, but Demkowicz is a specialist. For 30 years he has been studying adaptive finite elements, a highly technical modeling technique that strives to understand the larger behavior of a phenomena or structure by breaking it into pieces represented by mathematical equations.

Demkowicz, who is also a member of ICES Multiscale Modeling group and Predictive Engineering and Computational Sciences center, applies the technique to math and software related to wave propagation. It's a broad topic that has him helping to develop the numerical foundation behind high-tech simulations in fields ranging from optics, acoustics, mechanics, fluids and electromagnetics.

"The intellectual part may dominate if you're working on theory of numerical methods, as I do," said Demkowicz. "But the problem always starts with practical applications and the need for this type of theory for these applications."

For example, Demkowicz helped develop a code that can accurately compute values that don't have digits appear until the trillionth value space. That's a stream of 12 zeroes before a non-zero value appears. The sensitivity of the code pushes computing to its physical limits, nearing the 15th digit maximum that computers can accurately read.

On its own, computing the tiniest of numbers might all seem like mathematical puffery. To the oil and gas industry it has some very real uses. Before oil is drilled, tools are sent down the borehole that send out electromagnetic waves that sense the composition of the surrounding rock. However, the cement and metal casing of boreholes weaken the signals by a factor of 12 by the time they are read by the tool's receiver. Using Demkowicz's code, companies can accurately represent the wave receiving strength when creating simulations used to test and develop sensitive borehole technology.

"If you take standard methodology or code people will laugh at you. They will say that it is impossible," said Demkowicz. "But we delivered the impossible."

Passing the math test

To a non-mathematician, explaining the math that enables adaptive finite element methods can be like speaking a foreign language. Demkowicz says he has a friend that, when questioned about his profession, distills his work with numbers into the simplest of terms.

"He says that he's an accountant."

Still, how the technique is used to build simulations and can be broken down into four general steps:
mathematical analysis, discretization, verification and validation. The first step represents the problem, say modeling the wing of an airplane, through representative mathematical equations and then reviewing the work with what Demkowicz calls "mathematical sanity checks" to guarantee that the numbers and computing methods make sense.

The second step, discretization, converts the partial differential equations (which can produce results ranging to infinite values) used in the first step into algebraic equations with more concrete values. The last two steps are final checks. Verification, which has various stages, checks the code for errors that occurred in earlier steps. And validation puts the final simulation to the test in the real world by testing it experimentally.

"Only after you have managed to build all this machinery to solve the problem numerically, after you have built the code that computes the flow around the aircraft, can you design the aircraft," says Demkowicz. "Before you put a few human beings on an Apollo rocket and send them to the moon, you want to make sure they have a chance to come back."

Demkowicz's research will often focuses in on the details used in the first three steps. Engineers and experimental scientists take over once a simulation is ready for validation.

Computing discoveries

Demkowicz's numerical modeling methods have resulted in simulations that showcase interesting—and sometimes unexpected—phenomena. One simulation, currently under publication review, found that the reason some sounds can still be heard even when the ears are plugged could be due to a vibrating brain.

The project, which was initially sponsored by the U.S. Air Force, showed the brain acting like an alternate eardrum, resonating in response to sound waves. But instead of the waves being transmitted to hearing organs through the ear canal, they traveled through cranial bone.

"Those vibrations are transmitted in a much more sophisticated way to your cochlea where they generate electrical signals in your brain that produce the sense of hearing," said Demkowicz, plugging his ears with his fingers. The simulation results are still waiting to be confirmed through validation.

In an earlier project, Demkowicz helped develop a simulation that mapped eardrum pressure by analyzing the frequency and direction of an incoming sound wave—a relationship called the "head-related transfer function." The simulation, in effect, shows the different eardrum pressures associated with hearing different sounds.

It's technique that Demkowicz says could be applied to develop alternative methods for tuning hearing aids, which usually rely on simply asking patients if their hearing has improved—an option that's difficult to apply in infants and young children.

The resulting simulation imagery is often attractive and interesting; a multi-colored human head, the negative space of the human ear canal or air moving around an aircraft. It's a much more palatable representation for an outsider than pages and pages of mathematical proofs and equations that are the basis of the simulations—and that makes Demkowicz wary about relying on them too much to represent research.

"If I go up [to laypeople] and show pretty pictures of airflow around an aircraft, or vibrations of a submarine or propagation of acoustical waves in the skull and I tell them this is what I do, but not what it takes to do I, it completely trivializes the problem," said Demkowicz.

"Pretty pictures are for illustration and for enhancing our understanding. The final result if always hard core numbers."

The human factor

No matter how computationally intensive the research is, and how much he emphasizes the math, both Demkowicz and those that work with him say that a key component to conducting science is the human element.

"If there is one thing I have learned from Dr. Demkowicz, it's that no man is an island," says graduate student Jesse Chan, who is researching techniques in computational fluid dynamics with Demkowicz.

The extreme levels of specialization within computational science requires scientists to come together, and put their heads together, to perform useful research, says Demkowicz. And the methods that a team or contributing individual creates can often be better understand by simply knowing more about the people involved; where they're from, whom they studied with and their life influences.

"I always emphasize that science, like any other field, is very personal," said Demkowicz. "And one shouldn't lose the personal aspect of doing science because it provides a key to the understanding of why people think one way or another."

Demkowicz takes his own advice: One of the most noticeable parts of his office is a large yellow poster showcasing Polish mathematicians. Each name is accompanied by a photo and short biography. Demkowicz, a Poland native, shares with them a common heritage and interest in mathematics—but the similarity ends there, he insists: "Those are the greats!"

But during his 20 years at ICES, and ICES predecessor TICAM, Demkowicz has achieved his own notable accomplishments. He is founding member of the institution and serves as its assistant director. He's editor-in-chief of the *International Journal of Computers and Mathematics with Applications* and sits on the editorial board of ten other journals. And before ICES was created, Demkowicz served as the founding member and the first president of the Polish Association of Computational Mathematics.

That's not mentioning the research sparked by phone calls from basic research minded—or simply stumped—industry and government agencies.

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