# EDITORIAL

## The Ultimate Question

*Greg Goetchius, Contributing Editor*

How many channels does it take for an engineer to solve a noise control problem? Answer: 42. Yes, that's right, 42. Why? Because according to "Deep Thought" (the hyper-intelligent computer from Hitchhiker's Guide to the Galaxy) that is the answer to the ultimate question about the meaning of life, the universe and everything. Deep Thought goes on to explain that this answer is incomprehensible, because the beings who were asking it didn't know what they were asking. I suspect Deep Thought might answer the channel-count question the same way and for the same reason.

I have debated with many colleagues for many years about the right measurement approach to solving noise problems, and the discussions always drift toward how many measurement channels should be used. Some say, "As many as you have." Others say, "None." There is never complete agreement, but in all of these discussions, I have noticed that people tend to gravitate toward one of two extremes.

On the one extreme are the "tire kickers." These are the clever ones who are sure they can intuit the solution to a problem simply by looking, listening, feeling, tapping and thinking. On the other side are the "channel-count champions," who not only use every transducer and channel they have available to them, but will add even more if they can beg, borrow or steal from someone else's setup.

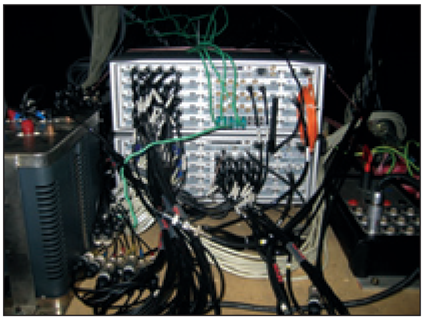
Tire kickers tend to ignore how complex large systems can be (like an automobile) and can often oversimplify both the problem and the solution. Armed with only their senses (and sometimes a long screwdriver), they quickly find and pronounce their solution to the problem.

Most of the ones I know who lean in this direction do have a fairly strong theoretical foundation in vibration and acoustics (and a few gray hairs), so their observations and educated guesses can actually be fairly accurate. Often, however, they can completely miss. Right or wrong, they get to an answer very quickly since kicking tires doesn't take that long and doesn't require fancy facilities like wind tunnels, test tracks or dynamometers. Just get in the car, drive around a little bit, kick the tires, pop the hood, stick your head in there, think about it some, and voila! There's your answer.

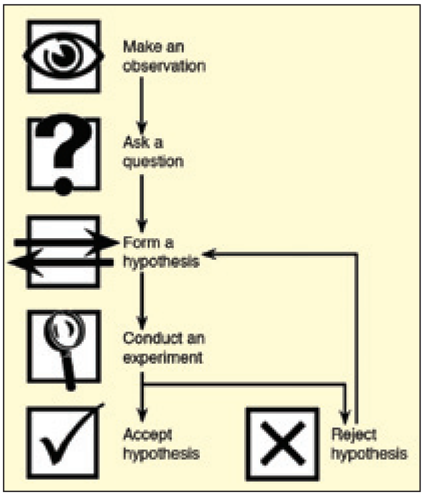
Oh, were it so simple.

Channel-count champions tend to worry too much about how complex the system is (and therefore, the solution) and are always in a state of: "I'm sure I missed something by not measuring that one last location." More is always better. Better to cover everything

*Engineer listening to a "vibration probe" to diagnose an engine problem.*



*Typical high channel count test setup.*




*Graphical schematic of the scientific method.*

with every conceivable kind of transducer and new measurement technology available (scanning lasers, acoustic holography, etc.) and hope that the answer will reveal itself in all of that data.

While often armed with a strong sense of noise and vibration theory, channel-count champions more easily set aside what physics might suggest to them and let the data speak for itself. The solution is surely there, you just need to dig through the data to find it.

Oh, were it so simple.

Clearly, I've portrayed both of these extremes rather harshly since I think that because they are at the far extreme, there is weakness in both approaches. In the real world, most engineers I know are somewhere along the continuum between these two and actually blend both into one problem-solving approach.

You may be wondering where I fall on this continuum. Interestingly, I have observed a clear trend in my career: I started off in my youth as a channel-count champion and have slowly but irrevocably shifted towards a tire kicker. Even back in the mid 1980s, when a 20-MB hard drive was considered huge, I threw every channel I could at the problems I worked on. I remember the mother of all operating-deflection-shape (ODS) tests I performed using a 128-channel "mobile" data acquisition system strapped to the bed of a pickup truck with a wire bundle from the transducers the size of a fire hose lashed to the frame. I used every channel. It took me weeks to setup and debug and weeks to go through all that data. Did I solve the problem? You bet I did.

After thinking about it, I actually think this evolution is natural. The older I get, the wiser and more experienced I become (hopefully), which allows me to form more insightful hypotheses, which then minimizes the testing I may need to do. Or maybe I'm just getting lazy as I age. Probably some of both.

In our NVH team at Tesla, we have a very rich mixture of channel-count champions and tire kickers, and the discussions on this topic are lively and often entertaining. We've been recently discussing the need to perform a transfer-path analysis (TPA) on one of our cars, and it was interesting to compare the reactions of various people on the team.

TPAs are complex data acquisition and data analysis exercises that require many transducers, dedicated test facilities, controlled operating environments, big channel counts and lots of data crunching. Over the years, I've done my fair share of these, and the thought of doing another one causes me to cringe. (Remember, I'm old and lazy.) However, the eyes of our channel-count champions shone brightly with anticipation of doing such a cool, big-channel-count test. It is such an interesting contrast. The cool thing is that we're both right: we'll start by kicking the tires, and then we'll hit the problem hard with a full-blown TPA – but with clear direction from the tire-kicking exercise.

I like this approach, since even the most technologically advanced technique (like a TPA) is much more powerful when aimed in a particular direction. A laser beam is extremely powerful and requires amazing technology to make work, but if not aimed at something, it is of little use.

So this brings me to the point I've really been wanting to make. I still believe in the scientific method. I remember first learning this in sixth-grade science class, and I have lived by it as an engineer ever since. The Scientific Method simply says:

*Develop a hypothesis and then perform a test which is specifically designed to confirm or deny that hypothesis***.**

Nothing more, nothing less. The information learned from this can either be the solution itself, or can lead to another, more informed hypothesis. In my experience (and in my humble opinion), this is the best way to get to a solution.

I contrast this with a brute-force method, which eschews physics and experience and just plows through a big matrix of test conditions, lots of channels and lots of data with the understanding that eventually the answer will be forced out of hiding. DOEs, Red-X studies, Shainin methods are all examples of this. They have their place, but most of the noise control problems I have ever worked on were much better suited to the old scientific method.

Here is my approach for automotive NVH problem solving:

1. Stop. Don't measure anything. Quiet your mind. Study the problem. operate the car. Operate the car some more. Talk to your colleagues about it. Kick the tires. Think. Doodle on paper (or maybe a spreadsheet). Think some more. Read a technical paper or two. Write some equations. Draw some graphs. Think one last time.

2. Develop a hypothesis. Based on all that driving, kicking, thinking, reading, doodling and discussing, you should have some decent ideas about what might be happening.

3. If you can, test the hypothesis quickly with a "book-end" test to see if your hypothesis is even close. For example, if you think a resonance is the root cause of some noise or vibration problem and you are able to easily throw some mass at it to shift the frequency, and the observed behavior improves, degrades or changes in a way that is consistent with the physics you believe are at play, then this was a successful book-end test. Keep going. Use your smartphone app (lots of good ones out there) to make a quick measurement to see what the frequency and/or amplitudes look like of the condition.

4. Refine your hypothesis and develop a specific test to see if it is correct. Make a change to the car and measure only with the number of transducers and channels needed to test your hypothesis. Did it work? Great! Does it make sense and jive with your hypothesis? Even better. Now you have to figure out how to put that change into production. (That's sometimes a harder job than actually finding the solution.) Not so much? OK, keep going.

5. Now it's time to bring in the channel-count champions. Go ahead and measure away, but do so with a clear direction and focus on what you are expecting. Be careful not to be too wedded to your initial hypothesis, though. You may be blinded by something unexpected that the big-channel-count test is trying to tell you but goes against your initial ideas. Keep an open mind. Noise is not stupid.

6. While you are analyzing all the data, keep your hypothesis in the forefront of your mind. Remember your doodles, the technical papers, the equations you wrote. The early results of your analysis better look a lot like what you thought about in Step 1. If not, stop. Double-check everything: all your instrumentation and data acquisition setups. Double-check your own thought process that led you this particular hypothesis. Were you assuming linear behavior when possibly there is a nonlinearity at the core of the problem? Were you assuming airborne noise radiation when it was structure borne all along? Never stop thinking, and never rely on the analysis software to develop the solution. That's your job.

Based on everything you have learned from this process, make a change to the car that you are sure will "solve the problem" and confirm that it works. If you've done the steps outlined above, there is a high probability that you will have a winning solution on your hands. Happy testing! S/V

The author may be reached at: ggoetchius@teslamotors.com.