# EDITORIAL

## Richard H. Lyon – Sounds of Quality Products

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Richard H. (Dick) Lyon is a Professor Emeritus in the Department of Mechanical Engineering at MIT, recipient of Silver and Gold medals from the Acoustical Society of America, recipient of the Gold medal from the Acoustical Society of India, member of the National Academy of Engineering, and fellow of both the Acoustical Society of America and the Institute of Noise Control Engineering of the USA. In addition to his professorship at MIT, Dick has served as Director of the Physical Sciences Division and corporate vice president of Bolt Beranek and Newman, co-founder of Cambridge Collaborative, founder and president of RH Lyon Corp, and a chief scientist at Acentech.

Dick Lyon has contributed to technical understandings of product sound quality, the interaction of sound and structures, machine dynamics, random vibration, sound generation, transducer design, the application of statistics to engineering analysis, as well as the development of techniques for understanding machinery noise, and the use of vibrational and acoustical signals for machinery diagnostics. Dick is a co-developer of Statistical Energy Analysis (SEA), a method for predicting the transmission of sound and vibration through complex structural acoustic systems that is particularly well suited for system-level response predictions at higher frequencies.

Here we want to focus on his decades of contributions to product noise and product sound quality engineering.

It has been said that Dick Lyon is the "father of product sound quality engineering." Forty years ago, Dick founded RH Lyon Corp to provide consulting services specializing in product sound quality improvements together with noise and vibration evaluation and reduction in products, as well as machine condition monitoring. Dick, together with the staff he attracted to RH Lyon Corp, has earned a worldwide reputation for excellence based on successful consulting assignments on challenging projects for product manufacturers working together with their staffs in engineering, marketing, and sales. Examples of products for which Dick and his staff provided consulting services to manufacturers are listed at the end of this editorial.

Dick and his staff at RH Lyon Corp joined together with Acentech in 2005. RH Lyon Corp staff members David Bowen, Gladys Unger, Jim Moore, and Rhoda Belostock continue at Acentech providing ongoing services for a wide range of domestic and international clients. David Bowen serves as Director of the Noise and Vibration Group at Acentech.

**Product Noise Control Engineering.** While on the faculty at MIT, Dick's interest in product noise was piqued when the Singer Sewing Machine Company approached him. Singer perceived the noise of its then-current sewing machine as being unacceptable. Dick examined the mechanisms within the machine and concluded that the crank/slider was responsible for the majority of the noise. Other product and appliance manufacturers followed; Singer and Dick realized that manufacturers needed assistance both in identifying sources of noise and understanding the methods applicable to noise control. Early on, it became clear that "applicable noise reduction methods" went far beyond engineering principles and included the manufacturer's concerns about size, cost and aesthetics. Product noise reduction was best accomplished by nurturing a close working relationship between the acoustical engineer and the manufacturer's engineering, design and marketing teams.

At RH Lyon Corp, Dick and his team refined a process for identifying and measuring individual competing noise sources and their paths of transmission, resulting in a rank ordering of their importance. This process, which Dick refers to as a "noise audit," involves separating noise sources and measuring their individual contributions to the overall noise.

One approach, widely used by the group, is the "window technique." The window technique requires that all sources of noise produced by the product be attenuated (such as by adding barrier materials, ducting away airflows, etc.) until the resulting noise is significantly reduced. Then the "window" to each source is "opened" individually and the noise measured.

Other approaches involve operating individual sources by themselves (under representative loading) if possible, as well as applying various signal processing techniques to the total measured sound. Properly performed, the numerical addition of the individual sources will equal the total noise produced by the product, both in overall level and in spectral shape. To refine the details of the noise audit, additional measurements such as vibration, transfer functions, and rotational and flow velocities are sometimes required.

With the results of the noise audit the manufacturer knows which sources of noise are most important and can then embark on the most efficient path to address noise reduction using sound acoustical techniques adapted to the constraints of marketability of the product.

**Product Sound Quality Engineering.** Product noise reduction is almost completely objective, while product sound quality is subjective, involving psychoacoustics, people's responses to a product based on its sound. The same Singer sewing machine project just noted also led to Dick's decades-long interest in product sound quality. At the time, the group at Singer wanted its machine to sound more like a competitor's unit, the sound of which they considered to be their "reference standard."

Dick, in typical fashion, attacked this challenge from an engineer's point of view, trying to quantify exactly what it was about the sounds that people liked and did not like. Realizing that modifications of any sounds had to be grounded in engineering design (e.g., there were no "mixing board" knobs to turn for adjusting the sound), he and a graduate student came up with a concept that relied on separating out the sounds produced by the various components and mechanisms within the sewing machine.

Coupled with jury studies, this procedure enabled them to quantify the degree to which different components influenced subjective responses. Furthermore, by adjusting these individual component sounds to reflect what might be possible by physical modifications, a design tool was provided for specifying how the manufacturer could produce a new sewing machine that "sounded better" from a consumer point of view.

Dick has often used the example of a car door to illustrate how sound is related to products. Dick will say, "When you go to buy a car, you will open and close the door. If the sound of closing the door is sturdy and robust, you'll have confidence that the car is well-built. If the door sound is tinny and flimsy you'll be suspicious of the quality of the car."

Product sound quality is the discipline of determining these subjective responses. Dick has always been a big believer in the importance of context in product sound perception, since people usually have certain expectations when it comes to using products, and sound is one of these expectations. As an extreme example of this, he has often said something like, "You don't want your refrigerator to sound like a motorcycle, and you probably don't want your motorcycle to sound like a refrigerator."

Generally, product sound quality involves a study of quantitative responses of individuals to a well chosen set of sounds. Based on the aggregate of responses, the manufacturer gains information on what physical changes are required to improve the perception of its product. Two common types of studies designed to obtain statistically valid, quantitative information are paired comparisons and numerical ratings.

In a paired comparison study, listeners (usually referred to as jurors) are presented with two different sounds and asked to choose the one they prefer.

In a numerical rating study, sounds are presented individually, and each is rated by the jurors for some attribute, for example, "Based on the sound, how well is the product performing, or how reliable is the product?"

Other attributes might involve the sound itself; "How acceptable is the sound of this product?" The sounds presented can be those of competitor's products compared to the product under study. More typically, the individual sounds, which make up the product's overall sound signature, are recorded, separated and remixed to create virtual products. For example, the motor whine, the exhaust air flow noise, and the rhythmic sound of a beater brush in a vacuum cleaner might be extracted and then remixed in various proportions to create "virtual vacuum cleaners." The juror's ratings on each virtual machine can be statistically analyzed to determine and quantify which combination the juror prefers.

Because each sound is extracted from a particular element of the product, the preference rating can be directly related to the mechanisms of the product. If jurors prefer less motor whine and more flow noise, for example, the manufacturer is guided in the redesign.

Manufacturers are interested in studying the sound quality of their products for a number of reasons. Generally, market share is the motivating factor. Market share can be affected when competitors introduce new product lines or when major redesign is being considered. In some cases, manufacturers are interested in understanding how consumers will react to a product they are unfamiliar with. When a new type of top-loading washing machine with a very different agitation mechanism was introduced, the RH Lyon team performed a jury study, first to understand the relationship between the acceptance of the new machines and their sound, and second, to optimize that acceptance, based on the juror's responses to the set of virtual machines.

Sometimes a manufacturer is interested in entering a new market, such as trying to sell a product in a different country, where sound expectations of users may be significantly different than in a current home market. Dick and his team conducted a sound quality jury study in China to determine how to redesign a product to gain better acceptability in that market.

**Generalizing Product Sound Quality Engineering.** As described above, jury studies can be either product or model specific. They take the design space; the noise from components such as motors, brushes, and air flow and map that into the perceptual space – well made, reliable, acceptable, etc. But the information cannot be generalized. Taking a page from the food and flavors industry, Dick Lyon and his team explored methods to determine a "sensory profile" for sound that could be used to predict user perception for a particular class of products.

To illustrate, consider this example from the food and flavors industry. A manufacturer is developing a new low-fat peanut butter. The primary components for peanut butter, which have been established, might include peanut flavor, saltiness, sweetness, and bitterness. The perception of interest here might be satisfying taste. The manufacturer presents only the new peanut butter to a panel of expert tasters. The tasters rate the peanut butter for saltiness, bitterness, etc., and a numerical rating of the sensory profile results. That result can be compared to the known profiles for existing brands.

The equivalent approach in acoustics would include a panel of expert listeners rating a new product sound and comparing it to a previously established sensory profile. Dick Lyon and his team explored this approach using a grant from the National Science Foundation.

More recently, the group has explored an alternative approach, replacing expert listeners with sound metrics. Because sound metrics can be calculated directly from the sound, identifying a way to create a sensory profile numerically related to sound metrics would eliminate the need for either additional jury studies or expert listeners. The team explored this concept by applying a series of metrics to the sounds of a jury study of lawn care equipment that had already been completed and for which the juror's responses were known. Twenty-five metrics were considered, and it was found that four principal components could account for 85% of the user's perception. These components could be loosely translated metrics related to loudness, modulation, tonality and impulsiveness. Each component was made up of a weighted average of five to seven individual metrics. If modifications to the product were being considered, the principal component score of the sound of a prototype product could be calculated by applying the weighting to the metric.

Some sound quality and noise control projects worked on by Dick Lyon and his engineering team:

**Consumer Products**
- Golf clubs
- Vacuum cleaners
- Dishwashers
- Air conditioners/dehumidifiers
- Combination convection/microwave oven
- Electrically powered window shades
- Mobile home furnaces
- Top-loading washing machines
- Front-loading washing machines
- Electronic gas stove ignition
- Combination ovens, convection/microwave
- Powered tooth brush
- Blenders/food processors
- Camera
- Refrigerators
- Hair dryers
- Garage door openers
- Flat-panel TVs
- Fans/air purifiers
- Sewing machines
- Plug-in air fresheners
- Mechanical baby swing
- Game box
- Cell phone
- Toys

**Office Equipment**
- Laptop computer speaker
- Copiers
- Digital projectors
- Computer hard drives

**Medical devices**
- Cough assist unit
- Sleep apnea devices
- Oxygen concentrators
- Centrifuges
- Biopsy devices
- Surgical facemask
- Cardiac assist device

**Power Tools**
- Airless paint sprayer
- Shop vacuums
- Pumps
- Compressors
- Air-powered tools

**Lawn and Garden Equipment**
- Riding lawn mower
- String trimmers
- Mosquito control device
- Leaf Blowers

**Other**
- Split blade fan
- Diver's air regulator
- Night-vision goggles
- Liquid soap dispenser
- Home heating boiler
- Windshield wiper motors
- Golf cart motors
- Elevators
- Escalators
- Unmanned aerial vehicles

Dick Lyon is the author of three books; *Machinery Noise and Diagnostics*, *Designing for Product Sound Quality*, and (with Richard DeJong) *Theory and Application of Statistical Energy Analysis*. SV

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