Engineering a Quieter America:
Progress on Consumer and Industrial Product Noise Reduction

A TQA workshop and International INCE symposium

sponsored by

The INCE Foundation and the Noise Control Foundation

organized by

The INCE Foundation

hosted by

The National Academy of Engineering, Washington, DC

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PREFACE

The *Technology for a Quieter America,* (TQA) report was published by the National Academies Press in October 2010 following a five-year study by the National Academy of Engineering (NAE) of the environmental noise situation in the United States. The report includes findings and recommendations for government, industry, and public actions that may mitigate or eliminate those noise sources that pose a threat to public health and welfare.

In 2011 the Institute of Noise Control Engineering (INCE) Foundation and the Noise Control Foundation established a TQA Follow-up Program to identify specific noise topics and to develop relevant recommendations aimed at improving the noise climate in the United States. The TQA Follow-up Program consists of a series of events involving experts in selected TQA topic areas to further assess specific noise issues and publish a series of recommended remediation measures.

This report presents the results of one TQA Follow-up event, a workshop titled *Engineering a Quieter America: Progress on Consumer and Industrial Product Noise Reduction*, which was organized and/or sponsored by the INCE Foundation, the Noise Control Foundation, INCE/USA, and International INCE. The workshop was hosted by the NAE at the National Academies Keck Center, Washington, DC, on October 6 and 7, 2015.

The workshop and this report address the contributions of noise control engineers to improving both quality of life and the U.S. economy by providing domestic manufacturers with the expertise to develop, produce, and sell the quieter products now demanded by global markets. Expected future noise control engineering technologies are also addressed.

Thirty-one persons attended the workshop, with presenters representing manufacturers, consultants, trade and standards associations, universities, and a widely known consumer publication. Many attendees had 30 to 40 years of direct engineering experience in consumer at-home products or industrial products.

The workshop addressed consumer products ranging from automobiles to yard-care leaf blowers, and industrial products ranging from air-moving devices to valves. Products ranged from small hand-held devices to million-pound off-road trucks.

Appendix A provides the agenda for the workshop. Participants and their affiliations are identified in Appendix B. Appendix C provides a list of acronyms, abbreviations, and units in this report.

2.3 SOUND QUALITY AND ENGINEERING NOISE CONTROL OF VARIOUS CONSUMER PRODUCTS

David Bowen - *Acentech Incorporated*

Carefully considered noise control engineering methods can prove invaluable in consumer product design. During development, accounting for consumer perceptions—not just objective metrics—is key to creating a winning product.

David Bowen, with acoustical consulting firm Acentech Incorporated, shared his expertise in the area of consumer product noise. His knowledge is based on more than 25 years working with the gamut of consumer and medical products such as those listed in Figure 2.3-1. Bowen opened with some general impressions:

- Many products actually seem to be getting louder, largely driven by the desire for more powerful products that are lower in cost and lighter in weight.
- More products are placed in living areas—washing machines on homes' main floors and air purifiers in bedrooms, for example.
- Expectations are changing. For instance, the desire is for a robotic vacuum cleaner that can clean the floor without noise to distract a homeowner trying to focus on another task.

In noise control engineering, "noise audits" are a useful way to identify and quantify the sources of excitation, the path, and the radiation mechanisms. Figure 2.3-2 sums up the methodology based on this noise audit concept. Identifying the sources requires the isolation of each sound source, which can sometimes be accomplished by covering up the entire product—with lead sheet, for example—and then exposing a single source, or by relying on appropriate forms of signal processing.

Having identified the component sounds, ranking them based on their contributions to total noise allows priorities to be set for sound reduction. This method, Bowen said, "enables you to find an effective path for noise reduction engineering."

Quiet product design is a cost-effective means for decreasing noise. The design analyses can be supported by noise audit results from earlier models or competitor products. In the course of designing a product to decrease noise, performance is sometimes also bolstered.

Next, the presenter discussed an Acentech project to produce a quieter electric toothbrush, illustrated in Figures 2.3-3. Acentech identified noise emanating from the handle as the main source, even more than the brush and motor. By vibration isolation of the toothbrush gear drive from the handle, overall noise was decreased by approximately 7 dB(A).

Bowen next turned to foreign regulations as a driving force behind some noise reduction projects. His example: One client retained Acentech to reduce its vacuum cleaners' overall noise by 10 dB(A) to meet a European directive effective in 2016. Because companies may not want to manufacture two different product models, the U.S. can benefit from foreign requirements though this country is generally reluctant to impose its own noise limits.

Bowen next discussed sound quality, and how the ear/brain system shapes people's subjective response to sounds and to the objects producing them. Sound quality depends on a person's response, not a purely objective metric, and people's subjective responses depend on their expectations based on the product's function and the context of its use. Perceptions matter because, for example, a quiet vacuum cleaner may be suspected of poorer cleaning performance.

One major attribute considered in the context of user perceptions is “acceptability” of the sound. Factors affecting acceptability include strength and magnitude; annoyance value (bothersome aspects of sound such as roughness and sharpness); amenity value (pleasing aspects of sound such as regularity and harmonicity); and information content (related to the product performing properly).

Bowen next addressed the related subject of the importance of using listening panels that represent a cross-section of consumers and are not biased by an association with the manufacturer. These panels' preferences can guide product design goals and directions. To improve sound from a user perspective, these panel members are sometimes asked to weigh in on sounds from virtual products made up by altering sounds of components and mixing them together. From this type of study, experts can build a quadratic regression model, and beyond this, use principal component analysis to help form custom sound quality metrics that can correlate well with the jury ratings for use in future analyses. The approach's ultimate goal is a response surface contour that elucidates the path to a better design.

Among other examples of noise-reducing redesign, Bowen returned to the example of a vacuum cleaner, as summarized in Figure 2.3-4. He discussed the process of isolating the product's sounds and mixing them together in various steps for presentation to a jury. According to regression equations plotted in contour plots, the strongest contributors to the perceptions of acceptability and perceived power were the motor and airflow sound, and a higher level of rotating brush noise could increase perceived power without decreasing acceptability. By this step and further increasing acceptability by essentially redesigning the motor, Acentech achieved a 5 to 10 dB(A) reduction in broadband motor vibration level and a 6 dB(A) reduction in noise level.

Bowen's team has also examined the question of how much consumers would pay for better sound. In the case of a tractor priced at about $23,000, a jury heard pairs of tractor sounds and was asked, “What is the largest price difference you would be willing to pay for the tractor sound that you prefer?” On average, the highest price difference jurors were willing to pay was about $600 for, in this case, a cab over the tractor. In another study, this time on blenders priced around $150, jurors indicated they would be willing to pay, on average, about 50 percent more for a “quiet version.”

In conclusion, Bowen stated that while some consumer products are being designed to perform more quietly, the tendency seems to be for consumer products to instead become louder due to marketplace pressures for products that are lighter, smaller, and more powerful; this tendency also applies to new or significantly improved products. Bowen qualified this by stating “All those factors contribute to increased noise, or at least as consultants, those are the ones that we hear about, the problem ones.” From the manufacturers' perspective, while they understand the importance of sound quality to consumers, they still may not be prepared to invest in a full-blown sound quality study.

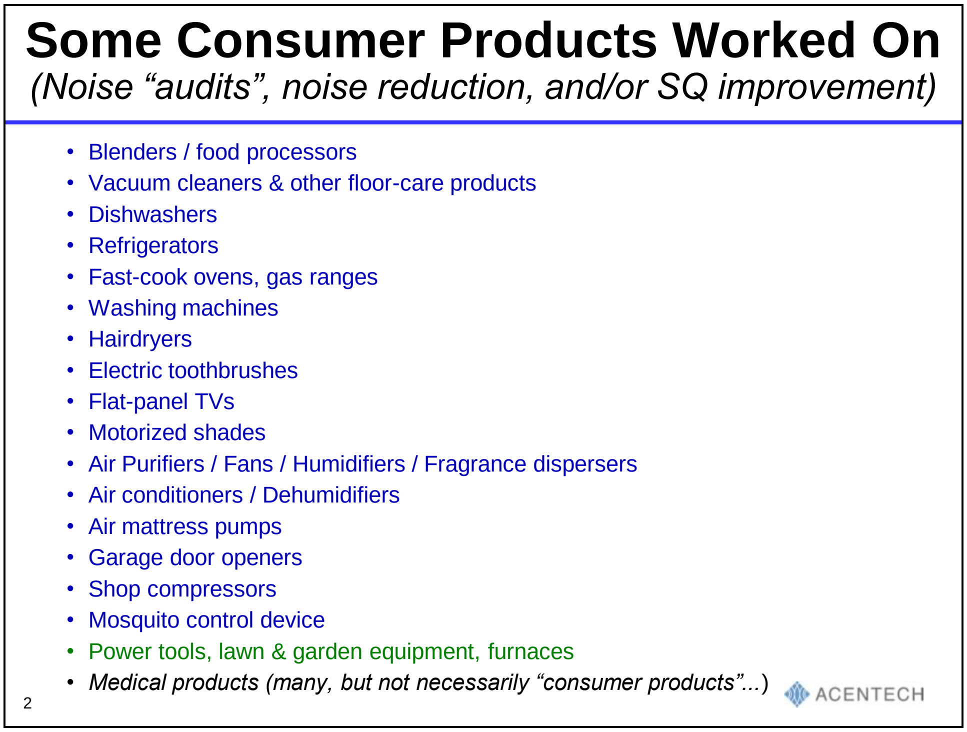


Figure 2.3-1 Consumer product examples.

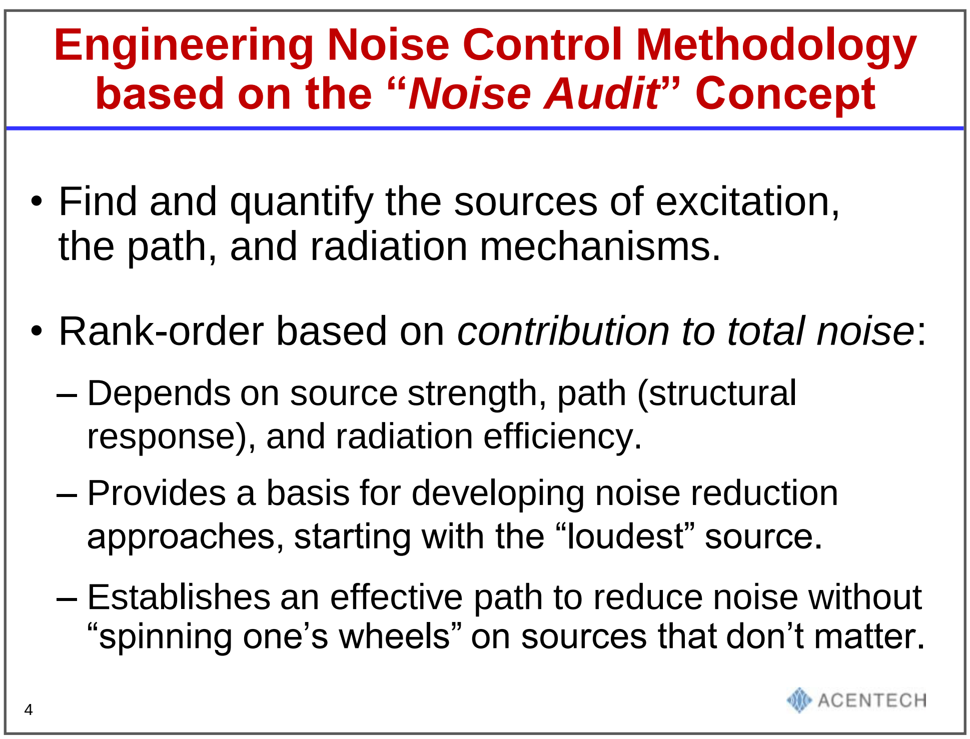


Figure 2.3-2 Conducting a noise audit.

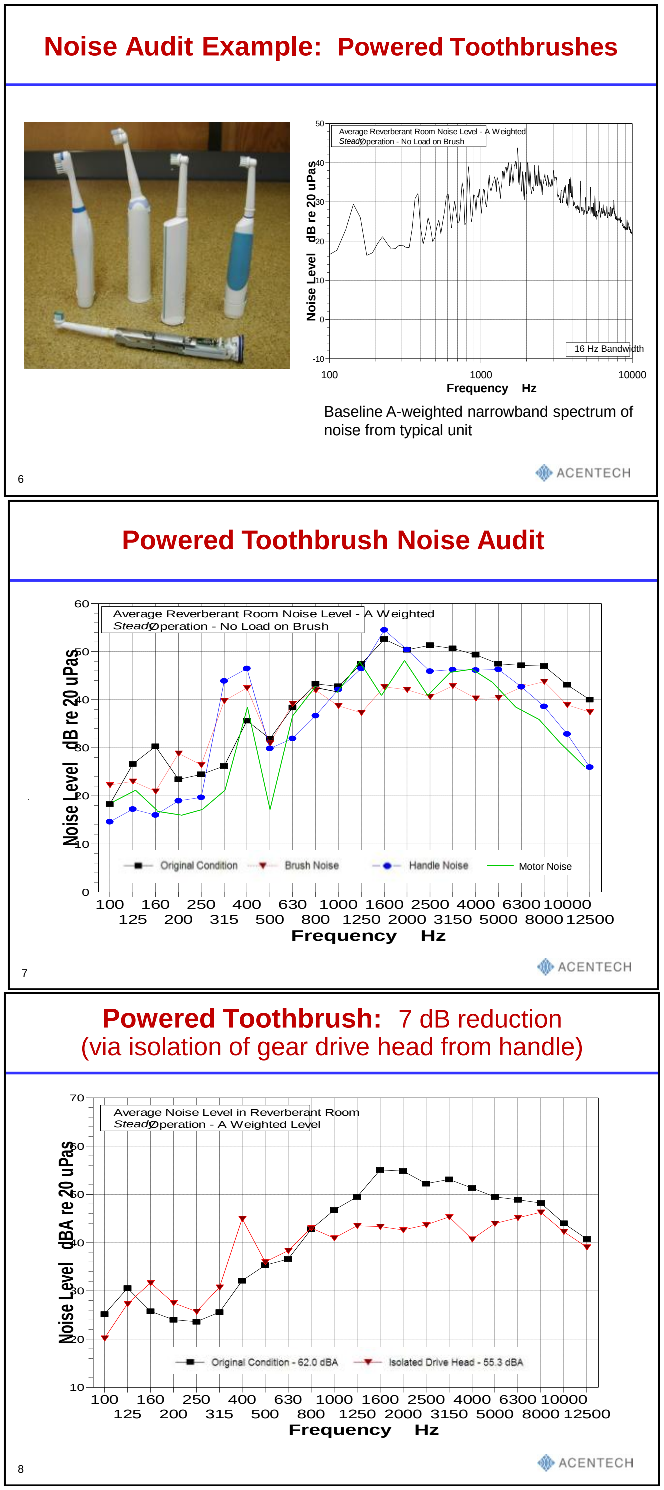
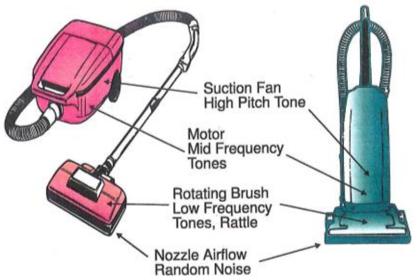


Figure 2.3-3 Creating a quieter electric toothbrush.

Vacuum Cleaner SQ Example

Main Sources of Noise



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Example Component Sounds for a Vacuum Cleaner SQ Study

BASELINE VACUUM CLEANER SOUND

- Motor (w/. cooling fan) Sound (**M**)
- Airflow Sound (**A**)
- Agitator (Beater) Sound (**B**)
- Suction Fan Sound (**S**)

SAMPLE SEQUENCE OF SOUNDS FOR JURY TEST, in "steps" (1 step = 4 dB):

	M	A	B	S
a.	+1	-1	+1	+1
b.	-1	+1	-1	+1
c.	-2	0	0	0
d.	0	0	0	0
e.	0	+2	0	0
f.	+1	-1	-1	-1

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Vacuum Cleaners
(Example jury test regression results - upright unit)

Acceptability = 35.7 - 1.2**M** - 1.4**A** - 0.2**B** - 0.06**M**^{2} - 0.03**A**^{2} - 0.06**MS** + 0.05**MA** - 0.06**MB**.

Perceived Power = 42.3 + 0.88**M** + 1.06**A** + 0.45**B** + 0.06**M**^{2} + 0.054**B**^{2} - 0.08**MA** - 0.06**AB**.

*Where **M**, **S**, **A**, and **B** stand for changes in the sound levels in dB for **Motor, Suction fan tones, Airflow**, and rotating **Brush** noise.*

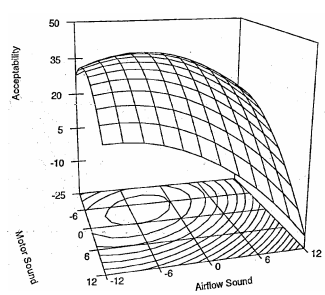

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Figure 2.3-4 Identifying ways to improve vaccum cleaner's "sound quality."