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Noise Control Engineering and Education

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Noise is often an unavoidable and ubiquitous byproduct of many systems and processes, and the more complex the system, the more difficult it is to accurately determine a priori its noise radiation characteristics. It is therefore considered more economical and effective to "design in" noise prevention measures in development than to try to "design out" using noise control techniques. In practice, however, most noise control engineering efforts address remediation and mitigation retroactively.

There is a tendency to oversimplify causes of noise and thus neglect it or equate it with vibration. Engineering curricula should clearly delineate noise and vibration and require consideration of noise in design projects whenever appropriate. A holistic systems approach in design courses can benefit from the inclusion of noise as a parameter. Educating design engineers and engineering organizations to consider noise issues as a design requirement would help in the management of noise problems, as is done in aircraft, submarine, and modern architectural design.

Noise Management: Aims and Stakeholders

Noise management generally implies reduction to acceptable levels as determined by standards, communities, legislation, and commercial competition. It also includes "shaping" noise by changing its characteristics, such as its spectrum, to make it less objectionable while retaining the signal (or information) it is meant to transmit, such as changes in an operating device or the approach of a vehicle. Noise management also concerns physical effects on structures, as in the case of sonic booms, and biological effects, as on marine life. Noise management efforts generally aim for quieter homes, workplaces, schools, hospitals, urban areas, and national parks, as well as quieter products and transportation for both communities and passengers.[1]

The pervasiveness of noise means it involves a variety of stakeholders with interests spanning quality of life, health, and economics—from technology developers and researchers to educators, users and consumers of products, businesses and industries, consultants, professional societies, governments, and the public. Federal, state, and local governments and agencies balance these stakeholder needs through policies, researchers develop new technologies to ease the apparent dichotomy between quality of life and cost, and educators contribute to the entire spectrum.

Management of the sound emitted from a source requires an understanding of its design and operational characteristics.

Noise control engineering more or less covers the range of stakeholders' interests and needs, and varies with institution type and size, from small businesses to large industries, regulatory agencies, and large and small consulting firms. Noise control engineering positions vary from a resident engineer who occasionally works on noise problems to full-fledged noise and vibration groups that include research and development.[2] The skills and knowledge needed by a noise control engineer include compliance, measurement, source identification, and suppression and inhibition of sound generation and transmission. In addition, the ability to communicate orally and in writing is important as noise control engineering directly bridges technology and society.

Understanding Noise Control Engineering

Noise control engineering follows the basic elements of noise control along the customary source-path-receiver model. Conventional wisdom advocates focusing on the noise source as the most effective approach, but this is not always possible or practical. Prevention or modification of the sound path (e.g., with barriers, walls, enclosures, or treatment with special materials) helps manage noise levels before reaching the receiver, individuals, or communities. When such methods become ineffective, receiver protection methods are employed.

Identifying Noise Sources

For noise reduction or management, a noise source can be considered a combination of *force* or *energy* sources and *acoustic* or *radiation* sources. Often, but not always, excitation that leads to sound radiation (emission) originates at a different part of the source system from where the energy reaches an efficient radiator of sound. Noise radiation from ship hulls due to diesel engines is such an example. Also, flow through a thin-walled metal duct excites the walls, which become the sound source.

Sometimes the force and sound sources are the same, as in the case of a car antenna that produces a whistling sound due to vortex shedding. Power generated by the pistons in a swash plate hydraulic pump propagates to other parts of, say, construction equipment with a crowded structure, and radiates sound from panels that it reaches. More common in multifamily dwellings is the noise of footsteps that radiates through the floor and the ceiling below.

Many complex noise sources have multiple force and acoustic sources within the system, making causal source identification more difficult. Noise control engineers use special techniques and instrumentation with signal processing capabilities to identify the sources. Management of the sound emitted from a source requires an understanding of its design and operational characteristics. These and other examples strongly suggest the importance of knowledge of diverse engineering disciplines in managing noise sources, as discussed later.

Emission, Transmission, Immission

Sound power, together with directivity, defines the inherent emission characteristics of noise sources and

[1] These subjects have been addressed in the report *Technology for a Quieter America* (NAE 2010) and in a related series of workshops (e.g., INCE-USA 2020).

[2] For a survey of noise control engineering resources, see Maling (2021) in this issue.

is usually reported as the A-weighted sound power level of a noise source. A-weighting approximates the perception of sounds by the listener with a single number (for a detailed discussion, see NAE 2010). Noise radiation then involves transmission, reflection, refraction, diffraction, absorption, and scattering as sound propagates through the environment and interacts with boundaries.

Transmission refers to force or energy paths, sound paths, and *flanking* paths (in which sound waves excite structure-borne sound waves to reach an otherwise isolated surface and radiate sound). Reducing the levels of direct sound fields before they reach a receiver, operator, home, or office generally involves barriers, walls, or enclosures. For outdoor barriers (e.g., along highways) and walls, material properties, cost, and durability play an important role.

Immission (what an individual hears) represents a source sound modified during transmission and/or by the environment in which the source and receiver are located. In an enclosed environment management of sound field requires knowledge of room or architectural acoustics, to be able to quantify the sound field by considering the reflection and absorption of sound and transmission through walls, windows, and vents. Free-hanging absorption materials in a factory help reduce noise, while balconies, ornate reliefs, and other configurations of assorted dimensions help distribute sound in a concert hall to achieve a more uniform and desirable acoustic energy density for the entire audience.

Methods for protecting the receiver from excessive noise (e.g., on airport tarmacs or near very noisy machinery in enclosed areas) include personal hearing-protection devices, such as earmuffs and noise cancelling headphones. Receiver protection also requires limiting exposure times, in keeping with established norms and legal restrictions. Knowledge of relevant ordinances, regulations, and standards is an appropriate part of noise control engineering education.

Useful, Annoying, and Luxury Noise

Although noise is described as unwanted sound, it can have useful applications. For instance, artificial or natural white noise helps mask annoying sounds, such as high-frequency squeals, and provides some privacy for conversations in offices and hospitals. Noise can also convey signals about the operation or health of a system or machine for diagnostic or detection purposes.

Conversely, submarines and helicopters need to reduce the noise they emit to avoid detection and identification. For supersonic aircraft to travel over land, efforts are underway to modify the sonic boom signature to reduce its detrimental effects on people and structures. Noise from drones, however, must balance between complete suppression to reduce disturbance and an adequate level to alert people in the vicinity to their presence for privacy.

Knowledge of psychoacoustics can help a noise control engineer assess the annoyance potential of noise.

Noise has a broad realm of impact that ranges from one extreme that can be considered “violent” (e.g., explosions) to the other extreme that can be called “luxury” noise (e.g., hush-quiet car interiors). With the abatement of dominant sources of noise in luxury cars as a result of advanced aerodynamic design and reduced engine, transmission, and road noise, previously unnoticed sounds have been “unmasked,” including those of the small electric motors that raise and lower the windows and antenna and power the small pump in the fuel tank.

It is worth noting that individuals respond to the same sound immission differently depending on who is operating the proverbial leaf blower, even if it is louder than one’s hairdryer. As distinct from deleterious health effects of very loud noise, annoyance resulting from noise can be summed up by quoting Milton (1644) out of context: its “annoyance and trouble of mind infuse it self [sic] into all the faculties and acts of the body….” Knowledge of psychoacoustics can help a noise control engineer assess the annoyance potential of noise. Psychoacoustics studies that date back to S.S. Stevens in the 1940s have regained renewed significance as engineering advances make it possible to modify the spectral content and amplitude of noise signatures to reduce annoyance or prevent speech interference.

Noise Control Engineering Education

The above discussion indicates that noise and thus noise control engineering represent more than a monolithic, narrow discipline. Awareness of, if not expertise in, a

BOX 1 Sample courses and areas of study for noise control education

BASIC – UNDERGRADUATE	
Dynamics	Basic acoustics
Vibrations – discrete	Noise and vibration control
Fluid dynamics	Measurement and instrumentation
ADVANCED – GRADUATE	
Advanced dynamics	Random vibrations
Advanced vibrations – continuous	Nonlinear vibrations
Advanced fluid dynamics – waves	Advanced controls
ADVANCED – SPECIALIZED	
Structural acoustics	Signal processing
Interaction of sounds and structures	Nonlinear control systems
Ocean/underwater acoustics	Wave propagation
Aeroacoustics	Ultrasonics
ADVANCED – SPECIALTY	
Psychoacoustics	Environmental noise
Audiology	Automotive noise
Audio technologies	Gear noise
Acoustics of music and speech	Thermoacoustics
Music technologies	Medical acoustics
Building acoustics	
NEEDED	
Design for low/shaped noise	

variety of subfields is a desirable attribute of an educated noise control engineer. Noise control engineering education should reflect the field's needs and practice, with a broad range and depth of applications relevant to many stakeholder groups.

Education should prepare noise control engineers to address myriad kinds of noise problems—in the home, workplace, urban areas, and national parks—and to design quieter products and vehicles. Since the effects of noise range from annoyance to harmful health impacts, noise control engineers must learn about policies and regulations intended to mitigate these adverse effects.

Preparation for Practice

Noise control engineers work in industry, government agencies, and consulting firms, and with technology developers, users and consumers, the public, and educators. The diverse interests converge through technology, policies, and economics to enhance quality of life and health. This convergence has an important role in noise control engineering education.

Noise control engineers' practice may be viewed as addressing three categories of problems: (i) well-defined, routine problems; (ii) complex system-level problems that have multiple parameters requiring optimization among them; and (iii) elusive problems without an immediately obvious solution. Problems in the second and especially third categories often require interdisciplinary backgrounds, advanced studies, and/or years of experience.

Academic preparation of a noise control engineer to deal with problems of different levels of sophistication and in different fields of application may include one or two courses as an undergraduate, a capstone project, an MS degree, and/or a PhD degree. Most such courses and programs are in mechanical engineering departments, but many interdisciplinary programs cover vibrations and acoustics as well as noise control.

Beyond academia numerous opportunities exist for nonspecialist degree holders such as short courses and online education. Occasionally nonengineers and non–degree holders also get involved in noise control engineering. In summary, multiple paths exist for noise control engineering education.

Curriculum

Noise control engineering education does not have a standard curriculum but relies on courses in selected aspects of noise control engineering. In addition to those listed in box 1, these may include aerodynamics, structural dynamics, physics, electronics, psychology, physiology, architecture, and statistics (Moss 2008).

Undergraduates who take at least two courses (and associated laboratories) in vibrations, acoustics, and noise control possess a strong foundation. A capstone project can help coalesce the knowledge gained in coursework and bring out practical aspects of noise control engineering problems.

In the absence of a noise control engineering curriculum, a master's degree in acoustics or noise control, with thesis, provides more depth and breadth than undergraduate courses and projects. Additional courses may cover topics such as continuous system vibrations, random vibrations, advanced-level acoustics, signal processing, psychoacoustics, and courses related to noise sources such as fluid dynamics and structural dynamics (Moss 2008). A graduate with a master's degree should be ready to build on this education by gaining experience working on noise control projects. The type of employment determines the additional breadth and depth of the experience gained.

A doctorate on a topic related to noise control is often awarded by a mechanical engineering, aerospace engineering, or physics department with a thesis that treats a noise control problem. Additional advanced-level courses and courses from other disciplines augment the research experience gained during development of a thesis. A doctorate better equips an engineer to address elusive and complex noise control engineering problems. The narrow and deep nature of a thesis may initially appear to confine expertise to a specific area, but the capabilities gained during the thesis work generally translate to most other applications and problems.

As with engineering education generally, experience gained from working on noise control problems is an irreplaceable education. Short courses offered by consulting firms may transmit years of experience and provide many "rules of thumb." With or without a degree, a good understanding of engineering principles can also pave the path to becoming an effective noise control engineer.

Challenges and Opportunities

Clearly, knowledge exists for educating and preparing noise control engineers. However, courses on noise control engineering are not part of the required undergraduate curriculum; they are elective and thus need to attract enough students to sustain them. Students may be drawn to courses in areas that appear attractive in the context of the job market. At the graduate level, students are generally supported by a research program, which may suggest employment potential following graduation.

Much academic research in noise control engineering has roots in large-scale funding from federal government agencies (e.g., underwater acoustics, aircraft noise). But in recent years support for noise research has decreased in favor of competing areas of study in new fields such as machine learning, nanotechnologies, bioinformatics, and genome studies. Many of these areas, as well as developments in metamaterials and sensors, for example, can enrich noise control engineering and education.

The challenge is to attract students to noise control engineering with sponsored projects that support faculty and student interests and research. Research can yield new ideas, insights, technologies, and approaches and thus excite and engage students, professors, sponsors, and even the public. And it leads to discoveries that can, for example, help mitigate emission and immission problems.

Responsibility falls on the noise control engineering community to draw on and incorporate new developments in areas to both advance the field and make it more attractive to students and employers. Integration of new technologies and discoveries—such as noise shaping with psychoacoustics, active control of vibrations and sound fields, AI for noise control at the design stage and for diagnostics, new measurement techniques with embedded nanomechanical sensors, and use of simulations and auralization[3]—all promise to enrich and bring new excitement to this field.

Experience gained from working on noise control problems is an irreplaceable education.

Emerging technologies such as electric cars and electric aircraft create new noise-related concerns and needs. What is the appropriate level and type of noise needed to ensure safety? Electric cars are adding a warning system for pedestrians. Trucks and other large vehicles are transitioning from timed beeping to a loud white noise when backing. In some airports, electric caddy carts alert pedestrians with a warning signal that may be objectionably loud. Noise control engineers have a role in developing appropriate emission and measurement technologies for these uses.

[3] Auralization is a procedure for modeling and simulating the experience of acoustic phenomena in a virtual space.

Anecdotal reports indicate that certain industries and government agencies need more noise control engineers, and may even provide in-house training in aspects of noise control.

Concluding Remarks

People everywhere are exposed to noise, whether at home, at work, or during travel or leisure activities, resulting in different degrees of irritation or risk. Laws and ordinances exist to protect the public from hazardous effects of noise. Noise control engineers have the expertise to develop and implement methods to meet regulatory requirements.

A public that is informed about noise mitigation technologies and methods would be more likely to demand solutions and ask for quieter products and processes. Professional societies should pursue partnerships with federal, state, and local governments to educate the public.

Funding agencies generally respond to ideas proposed by researchers to make a difference in a given field. Workshops that bring together researchers from industry, universities, and federal laboratories can identify research needs in a particular field to encourage funding agencies to support and give new life to education and research in that field. And special sessions at conferences can present new ideas for the development of new technologies for noise control.

Industry sponsorship of senior capstone or graduate projects is an opportunity not only to educate noise control engineers but for companies themselves to learn about the dimensions and impacts of noise.

Noise control engineering epitomizes the engineering profession since it clearly and directly pertains to technology and the public. The effective preparation of noise control engineers is an important responsibility for all stakeholders to ensure health and quality of life free of annoying and harmful noises.

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