Reducing Employee Noise Exposure in Manufacturing

Best Practices, Innovative Techniques, and the Workplace of the Future

a workshop sponsored by

The INCE Foundation, the Noise Control Foundation, and the National Institute for Occupational Safety and Health

organized by

The INCE Foundation and the National Institute for Occupational Safety and Health

hosted by

The National Academy of Engineering, Washington, DC

Cori Vanchieri, Rapporteur

edited by

George C. Maling, Jr., Eric W. Wood, Gregory Lotz, and William W. Lang

INCE

Institute of Noise Control Engineering of the USA

This report has been approved by the Board of Directors of INCE/USA for publication as a public information document. The content, opinions, findings, conclusions, and recommendations expressed in the report do not purport to present the views of INCE/USA, its members, or its staff.

Generous support for this project was provided by the International Institute of Noise Control Engineering, the INCE Foundation, and the Noise Control Foundation

ISBN: 978-0-9899431-2-3

Library of Congress Control Number: 2014945796

Printed in the United States of America

This report is posted on the INCE/USA website, http://www.inceusa.org

ORGANIZATIONS ADVANCING NOISE CONTROL ENGINEERING

The **International Institute of Noise Control Engineering** (I-INCE) is an international, nonprofit, nongovernmental consortium of more than 40 member organizations with interests in the control of noise and vibration that produce noise. I-INCE was chartered in Zürich in 1974 on the basis of Swiss Civil Law. The objectives of I-INCE are to sponsor annual international congresses on noise control engineering in the INTER-NOISE series as well as other specialized conferences, and to promote cooperation in research on the application of engineering principles for the control of noise and vibration. I-INCE undertakes technical initiatives and produces reports on important issues of international concern within the I-INCE field of interest.

The **Institute of Noise Control Engineering of the USA** (INCE/USA) is a nonprofit, professional-membership organization incorporated in 1971 in Washington, DC. A primary purpose of the Institute is to promote engineering solutions to noise problems. INCE/USA is a Member Society of the International Institute of Noise Control Engineering (I-INCE). INCE/USA has two publications, the *Noise Control Engineering Journal* (NCEJ) and *NOISE/NEWS International* (NNI). NCEJ contains refereed articles on all aspects of noise control engineering. NNI contains news on noise control activities around the world, along with general articles on noise issues and policies.

The Institute of Noise Control Engineering Foundation (INCE Foundation) is a nonprofit, tax-exempt, publicly supported, charitable organization established in 1993 and incorporated in New York as a Section 501(c)(3) organization. The purposes of the Foundation are to support, promote, and advance scientific and educational activities directed toward the theory and practice of noise control engineering and to promote and support such scientific and educational activities through grants, funding, and financial assistance to various individuals, institutions, and organizations.

The Noise Control Foundation (NCF) was established in 1975 to provide administrative services to the newly-formed INCE/USA. It is a nonprofit, tax-exempt organization incorporated in New York as a Section 501(c)(3) organization. At the end of the century when administrative support for INCE/USA was transferred to a commercial organization, NCF was re-chartered to be devoted to the development of national and international policies as related to the technological aspects of noise control engineering.

The National Institute for Occupational Safety and Health (NIOSH) is the U.S. federal agency that conducts research and makes recommendations to prevent worker injury and illness. The Occupational Safety and Health Act of 1970 established NIOSH. NIOSH partners with the Occupational Safety and Health Administration (OSHA). OSHA is part of the U.S. Department of Labor, and it develops and enforces workplace safety and health regulations. NIOSH is part of the U.S. Centers for Disease Control and Prevention, in the U.S. Department of Health and Human Services. It has the mandate of helping to assure every man and woman in the Nation safe and healthful working conditions and to preserve our human resources."

Workshop Steering Committee

W. GREGORY LOTZ
Co-chair, Director, Division of Applied Research and Technology, NIOSH

GEORGE C. MALING, JR., NAE
Co-chair, Managing Director, Emeritus, Institute of Noise Control Engineering

ROBERT R. ANDERSON
Principal, Robert Anderson Group, Inc.

DAVID HERRIN
Professor of Mechanical Engineering, University of Kentucky

WILLIAM W. LANG, NAE
President, Noise Control Foundation

MICHAEL J. LUCAS
Principal Engineer, Ingersoll-Rand, Rotary Compression Division

WILLIAM J. MURPHY
Leader, Hearing Loss Prevention Team, NIOSH

ERIC J. W. WOOD
Former Director, Noise and Vibration Group, Acentech Incorporated.

Technology for a Quieter America
Advisory Board

Preface

The report, *Technology for a Quieter America,* (TQA) was published by the National Academies Press in October 2010 and was the result of 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/USA), 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.

Two reports have been published. The first, "Noisy Motorcycles: An Environmental Quality of Life Issue" is based on a roundtable hosted by the National Academy of Engineering on October 24, 2012. The second, "Cost-Benefit Analysis: Noise Barriers and Quieter Pavements" is based on a workshop hosted by the National Academy of Engineering on January 16, 2014. Both reports have been approved for publication by the Board of Directors of the Institute of Noise Control Engineering (INCE/USA) as public information documents, and are available on the INCE/USA web site, www.inceusa.org.

This report is based on a third workshop hosted by the National Academy of Engineering (NAE) on February 19-20, 2014 in Washington, DC. The workshop title was "Reducing Employee Noise Exposure in Manufacturing: Best Practices, Innovative Techniques, and the Workplace of the Future." The workshop was sponsored by the INCE Foundation and was organized by the TQA Follow-on committee in cooperation with the National Institute for Occupational Safety and Health. Twenty-eight papers were presented, all addressing the subjects in the workshop title. The "best practices" theme was addressed in two ways: reports from major manufacturers about successful hearing conservation programs, and reports from engineers in industry, consultants, and government workers, on what constitutes best practice for noise reduction. Examples of successful implementations were presented. The theme of "innovative techniques" was addressed through new methods for noise prediction in manufacturing spaces, identification and localization of noise sources, new processes and techniques, and noise prediction. The third theme "the manufacturing environment of the future" was addressed by a general presentation on the future of manufacturing as being studied by a NAE committee, and some general thoughts by representatives of the National Institute for Science and Technology, and by the National Center for Manufacturing Sciences.

George C. Maling, Jr.
Co-Chair

W. Gregory Lotz
Co-Chair

Acknowledgements

This report has been reviewed in draft form by members of the *Technology for a Quieter America* (TQA) Advisory Board, all of whom are noted for their technical expertise in noise control engineering and acoustics. Many of the members contributed to the preparation of the TQA report published by the National Academies Press in October 2010, and now represent the continuing dedication of Academy members to a quieter America through the TQA Follow-up initiative, an excellent example of the National Academy of Engineering's (NAE's) commitment to the social value of engineering.

The support of the National Academy of Engineering in hosting the workshop described in the preface is very much appreciated. Thanks to Proctor Reid, director of the project office, and staff members Jason Williams and Vivian Chin.

Thanks also to the National Institute for Occupational Safety and Health (NIOSH) for assistance in the organization of the workshop, for assistance in identifying speakers from the hearing conservation community, and for several workshop presentations.

This report could not have been written without the assistance of rapporteur Cori Vanchieri. She wrote the summaries of all of the workshop presentations which were then reviewed by the authors. She had technical assistance from the editors and produced a very readable report.

The editors, George Maling, Eric Wood, Gregory Lotz, and William Lang put in many hours in the preparation of this report, and are grateful to all of the authors of the papers for their presentations at the workshop and for review of the summaries of their presentations.

The support of the INCE Foundation and the Noise Control Foundation is gratefully acknowledged.

Finally, thanks to the NAE's Committee on *Technology for a Quieter America*, chaired by George Maling, that produced the TQA report with its numerous findings and recommendations.

Contents

Appendixes

Executive Summary

This report contains summaries of the papers presented at a workshop hosted by the National Academy of Engineering in February 19-20, 2014. The title of the workshop was "Reducing Employee Noise Exposure in Manufacturing: Best Practices, Innovative Techniques, and the Workplace of the Future." Five major topics were addressed during the workshop:

1. Hearing Conservation Programs in Manufacturing Industries
2. Best Practices: Noise Control in Manufacturing Industries
3. Engineering for Noise Control in Manufacturing
4. Innovative Techniques for Engineering Noise Control
5. The Manufacturing Workplace of the Future

The papers in this report have, in some cases, been ordered differently than at the Workshop. The workshop agenda has been included as Appendix B of this report. Chapter 1 presents some general information on the scope and purpose of the workshop.

In Chapter 2, the workshop co-chair, Lotz, first addressed the hearing conservation theme by presenting information on the programs of the National Institute for Occupational Safety and Health (NIOSH), in particular, the "Safe in Sound" award which is given to companies with outstanding hearing conservation programs. Then Downey, Mulhausen, and Westrum described specific programs which have been implemented in their respective companies.

Chapter 3, the title Best Practices: Noise Control in Manufacturing Industries, was addressed by five speakers. For new facilities, a key element of planning is the computer modeling of the workplace and the noise level of the equipment to be installed. Probst shows how the CADNA(R) program can be used to model the workplace once the dimensions of the space, the sound absorptive properties of the surfaces, and the noise emissions of the equipment to be installed are known. He gives several examples of successful modeling. Because of the importance of this topic, a long version of the work is presented as Appendix A with a shorter version in the body of this report. The design of the equipment to go in the workplace is obviously an important factor for equipment manufacturers to consider. Herrin then presents information on the physics of low-noise product design. The next paper by Thompson includes information on the planning process used by NIOSH in the procurement of equipment in the mining industry where noise levels must be controlled. In the planning process, the user and the purchaser must know the noise emission levels of equipment to be installed, and emission standards facilitate the communications between buyer and seller. Murphy describes the key American National Standards for noise emissions. Finally, Maling describes "Buy Quiet" programs such as those developed by the National Aeronautics and Space Administration (NASA) and others. It is well accepted that the cost of noise control is lower during the machine design process than the cost of add-on solutions at the end of the design stage, or especially after the equipment has been delivered and installed. So the question has been asked: "Why buy a noise problem?"

The "best practices" theme continues in Chapter 4 with a series of papers on "Engineering for Noise Control in Manufacturing." This has some overlap with the next chapter, Chaper 5, on "Innovative Techniques for Engineering Noise Control" because the engineering solutions described here may very well have been innovative at the time they were implemented. Chapter 4 contains an overview paper by Bruce on what progress has (and has not) been made in the reduction of noise in America's manufacturing sector, and is followed by a series of papers devoted to specific engineering solutions for several sources. Wood discusses noise control for a manufacturing environment containing many sources. Stewart has two papers, the first devoted to a history of noise control in the textile, tobacco, and woodworking industries, and the second devoted to noise control of a shredding machine. Bruek discusses noise control at a metal conduit manufacturer, and Roberto and Tam cover several sources, including injector drills and vibratory feeders in a manufacturing plant.

"Innovative Techniques for Engineering Noise Control" is the title of Chapter 5. Lucas describes advanced aeroacoustic modeling techniques for the design of compressors, especially finite element techniques where the mesh "goes with the flow." He continues with new techniques for pneumatic tools. Anderson has long experience in the automotive industry and describes manufacturing techniques in that industry. Barnes describes how a shift in process, from reciprocating equipment to rotary equipment, can lower noise levels. More describes techniques for the reduction of noise from power generator sets. Finally, Taylor describes an innovative method for removing rivets from airplanes using an electro-discharge machining method. The project is called FRITA (Fastener Removal Improvement Technology Adoption), and is said to result in a safer removal process with lower noise levels. In the final paper, Barnes describes a change from reciprocating to rotary equipment in a candy plant.

In Chapter 6, the authors give us a vision of the manufacturing workplace of the future. This topic was added to the workshop agenda because the National Academy of Engineering (NAE) initiated a broad study of future manufacturing and the organizing committee felt that a glimpse of the future might give some direction to noise control engineering measures which might be needed in the future. Whitefoot presented an overview of the NAE program, Lilley gave a view from the National Institute for Standards and Technology (NIST), and Taylor gave her vision as seen by the National Center for Manufacturing Sciences (NCMS). In the final paper, Barnes describes what happens when sales and engineering personnel are on the factory floor.

1
INTRODUCTION

Background

Chapter 4, in the *Technology for a Quieter America* (TQA) Report[1] was devoted to control of hazardous noise. Several subjects were covered, including criteria for hazardous noise, broadband and impulsive noise, hearing protective devices, and techniques for controlling noise in industrial facilities. However, few examples were given of "real world" situations. Another article on industrial noise was prepared by Robert Bruce, a member of the TQA committee, in parallel with the TQA report and published in *The Bridge*, a publication of the National Academy of Engineering.[2] The article covered several techniques for reducing noise in industry. These included sources involving fluid flow, noise from machinery housings, machinery shields, barriers, and enclosures.

Recommendation 4-3 in the TQA report was directed to the Occupational Safety and Health Administration (OSHA) and its procedure for the determination of the allowable 8-hour noise exposure in the workplace.

> **Recommendation 4-3:** The U.S. Department of Labor should revoke the Occupational Safety and Health Administration (OSHA) "100-dB Directive" of 1983, which effectively raised the action point for engineering control of noise from 90 to 100 dB by allowing the substitution of hearing protectors for noise control up to 100 dB and thereby devastated the market for quiet machinery and equipment. At the same time, OSHA should reconfirm that engineering controls should be the primary means of controlling noise in the workplace.

At about the same time as the TQA report was published, OSHA published a proposal in the Federal Register which in effect would confirm that engineering controls should be the primary means of controlling noise in the workplace.[3] The method was, however, quite different from that in the recommendation above. For many years, OSHA had interpreted the word "feasible" as having economic and cost-benefit elements when considering engineering controls for noise. This meant that in many situations, hearing protective devices were a suitable solution—as stated in the recommendation above. In the Federal Register proposal "feasible" was defined as "capable of being done." American industry was not in favor of this proposal and many comments were received, including information on the costs of noise control—which, in many cases, were determined to be excessive. In 2012, OSHA withdrew the proposal, agreed to

---

[1] NAE. 2010. *Technology for a Quieter America*. Washington, DC: The National Academies Press. Available online at: http://www.nap.edu/catalog.php?record_id=12928

[2] NAE 2007. Bruce, R.D., Engineering controls for reducing workplacee noise. Washington, DC. Available online at: http://www.nae.edu/Publications/Bridge/NoiseEngineering/EngineeringControlsforReducingWorkplaceNoise.aspx

[3] *Federal Register:* Interpretation of OSHA's Provisions for Feasible Administrative or Engineering Controls of Occupational Noise, October 19, 2010. Available online at https://www.federalregister.gov/articles/2010/10/19/2010-26135/interpretation-of-oshas-provisions-for-feasible-administrative-or-engineering-controls-of#h-8 consult with persons from the NAE, and subsequently held an informal workshop attended by several members of the committee which produced the TQA report.

In 2013, the TQA follow-on committee considered several workshop topics, and concluded that a workshop on noise in manufacturing facilities would be of benefit to facility engineers in industry, government agencies, noise control consultants, and workers in high-noise workplaces. The committee felt that it would be best to partner with a non-regulatory agency, and was pleased to have the National Institute for Occupational Safety and Health (NIOSH) involved and Greg Lotz of NIOSH as co-chair. The workshop presentations are the basis for this report.

Scope

This report on a follow-up workshop hosted by the National Academy of Engineering (NAE) to implement the findings and recommendations of its *Technology for a Quieter America* (TQA) report.[1,4] The many references to occupational noise in the TQA report and the existence of both national and international regulations point to the importance of the control of occupational noise in America. The NAE currently has a project related to future manufacturing in the United States.[5] To be successful, future manufacturing must create value by integrating manufacturing, design, and innovation. This effort has implications for the noise environment on future manufacturing floors, which has further implications for the design of both manufacturing facilities and manufacturing equipment.

Content

Approximately a third of the workshop was devoted to the availability of effective low-cost techniques for the reduction of noise in industry, and design of low-noise machines for industrial use. The second third was devoted to techniques for reduction of noise through changes in industrial processes. The final third was devoted to the future manufacturing environment and its implications for new noise goals in manufacturing facilities. Lower noise goals will lead to the need to design low-noise machinery and equipment as well as low noise manufacturing processes.

[4] TQAPages 1, 2, 7, 8, 31, 33, 36, 37, 42, 49, 50 (Recommendation 4-3), 116, 117, 127

[5] NAE 2013. Making value: Integrating manufacturing, design, and innovation to thrive in the changing global economy. Washington, DC: The National Academies Press. Available online at http://www.nap.edu/catalog.php?record_id=13504

2
Hearing Conservation Programs in Manufacturing Industries

2.1 Introduction to the NIOSH Safe and Sound Award

W. Gregory Lotz, National Institute for Occupational Safety & Health

The National Institute for Occupational Safety and Health (NIOSH) has been involved in concerns about hearing loss since the inception of the Institute in 1970 and it still plays an active role. The NIOSH policy document, *Occupational Noise Exposure*, published in 1998, maintains a recommendation of 85 dB(A) for an eight-hour exposure limit with a 3 dB exchange rate.[1]

In 2014, NIOSH launched a web page for public use on controls for noise exposure. The Institute's goal for the workshop is to promote awareness of successful noise control programs and to talk about what can be done to advance awareness and encourage more industries to take an interest in good business practices and good technologies that are available. NIOSH shares these goals with the TQA Follow-up Committee, the National Academy of Engineering, and the INCE Foundation.

Noise-induced hearing loss has been a public health problem for decades. Hearing conservation programs need to be improved. Innovative strategies are needed. NIOSH tries to reach out and share information with scientists, policymakers and to publish guidelines and best practices.

In the United States, regulation is not a strong driver for noise control. NIOSH decided to offer awards and incentives, to create an award program to recognize effective programs and innovations and to promulgate the adoption of improved practices. The result is the Safe-in-Sound Award[2], launched in 2009 in partnership with the National Hearing Conservation Association.[3] The aim is to obtain information about real-world successful hearing loss prevention programs and public health practices used by industry and to disseminate those widely.

The Safe-in-Sound Award acknowledges companies that have demonstrated excellence in hearing loss prevention. Industries are invited to self nominate. Applications are submitted online and undergo a series of systematic reviews; selective site visits are conducted. Characteristics of the annual award winners were summarized and published in 2012 in the International Journal of Audiology.

Pratt & Whitney, winner of the first Excellence Award in 2009, had a cross-functional team including members from many different departments. They engaged the workforce to catalog all processes with A-weighted noise levels above 85 dB, then prioritized and implemented more than 500 successful noise reduction projects and "Buy-Quiet" initiatives.

The program has realized several positive outcomes. The award recipient earns important recognition within the company and effects are expanded in other parts of the company. They receive additional internal support for noise-control efforts. The award establishes credibility for innovative approaches and motivates the pursuit of additional program improvements. Personal commitments are renewed. New strategies are spreading corporate-wide and professional and government organizations are discussing new policies, guidelines, and/or procedures.

---

[1] http://www.cdc.gov/niosh/docs/98-126/pdfs/98-126.pdf
[2] http://www.safeinsound.us/winners.html
[3] http://www.hearingconservation.org/

Winners of the Safe-in-Sound Award:

Excellence Award	
2009	Pratt & Whitney – East Hartford Facility, Connecticut
2009	Domtar Paper Company – Kingsport Mill, Tennessee
2011	Shaw Industries Group - , Plant WM, Georgia
2012	3M, Hutchinson Plant – Hutchinson, Minnesota
2012	Colgate-Palmolive – Worldwide[4]
2014	Northrop Grumman Electronic Systems – Linthicum, Maryland
2014	Benjamin Kanters and Hear Tomorrow, Columbia College – Chicago, Illinois
2015	United Technologies Corporate Award
2015	MeadWestvaco Corporation – Cottenton, Alabama
Innovation Award	
2010	Etymotic Research, Inc. – Elk Grove Village, Illinois
2013	Johns Manville – Worldwide

Chapter 5 of OSHA Technical Manual (OTM), Section III provides technical information and guidance to help Compliance Safety and Health Officers (CSHOs) evaluate noise hazards in the workplace.

NIOSH would like to collect success stories and then share that information with others to promulgate effective noise control and show that it is feasible and good business. If worksites reported their results on reducing worker exposure, it would bring their noise control full-circle.

[4] A short description of Colgate-Palmolive's program is available in Appendix G of the OSHA Technical Manual (OTM) Section III: Chapter 5: https://www.osha.gov/dts/osta/otm/new_noise/#appendixg

2.2 Towards no noise-induced hearing loss; one company's journey

John Downey, Associate Manager, Global Industrial Hygiene, Colgate-Palmolive Company

The Colgate-Palmolive Company received from NIOSH the 2012 Safe-in-Sound Award (See the noise citation at the end of this article.). John Downey reported on successful noise-related aspects of Colgate-Palmolive Company's Environmental and Occupational Health and Safety (EOHS) system.[5] The company, which manufactures products for oral care, personal care, home care, and pet nutrition, employs 38,000 people in 35 countries. About 22,000 of its employees are engaged in manufacturing.

The company publishes global EOHS standards for all employees and all factories (Figure 2.2-1). Hearing conservation is one of many standards. Minimum standards are supported with guidance documents on best practices. Training and subject-matter experts are available to increase staff capabilities to implement standards. Finally, compliance is checked during audits and sharing of best practices and success stories.

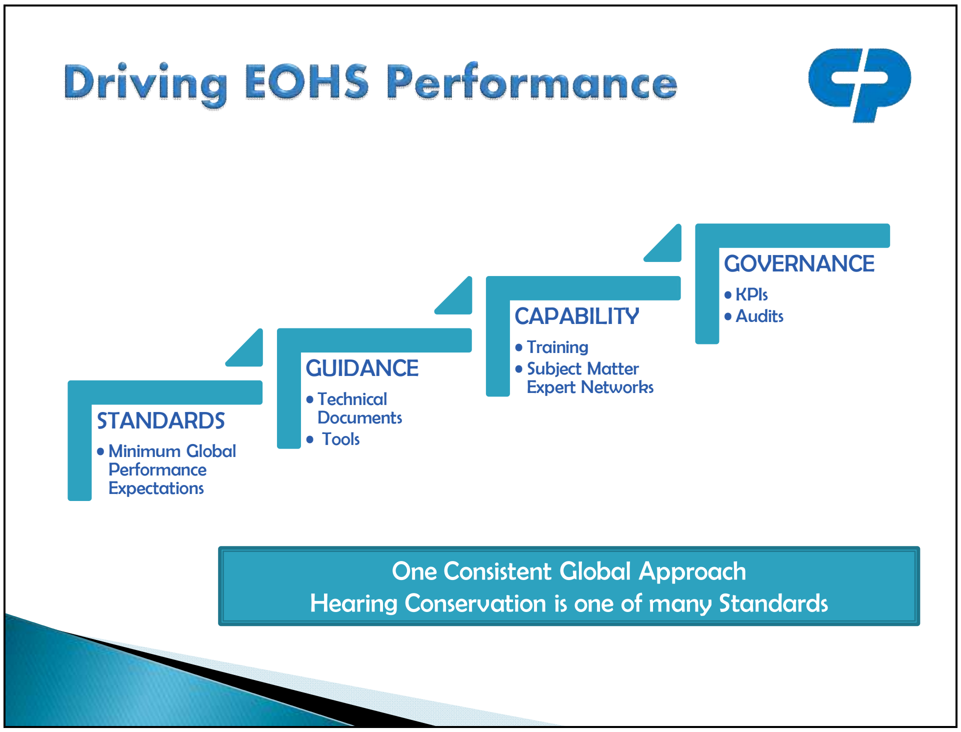


Figure 2.2-1 *Overall Strategy Addressing Environmental and Occupational Health and Safety.*

Colgate-Palmolive recently established a new global metric, or key performance indicator, for hearing conservation. The focus is the percentage of employees who would be over-exposed to noise during a working day without the use of hearing protectors. Colgate finds this metric, which focuses on measured noise levels, is a better option, offering more

---

[5] Colgate EHOS Policy Statement is available at:
http://www.colgate.com/Colgate/US/Corp/LivingOurValues/Sustainability/RespectForOurPlanet/EOHSPolicy%20081307.pdf

consistently precise numbers, than counting the number of employees who have incurred a noise-induced hearing loss.

The company has adopted the American Conference of Governmental Industrial Hygienists criteria for noise exposure of an 85 dB(A) threshold, a 3 dB exchange rate, and a 82 dB(A) action level. Its overall program for controlling noise exposures includes four basic elements:

- Designing quiet
- Reducing noise at the source
- Building capabilities
- Operating quietly

When purchasing new equipment for an existing factory, the company's global new-equipment specification standard requires purchasers to work closely with equipment manufacturers to achieve a target noise level not exceeding 80 dB(A) when measured in isolation at 1.5 meters during, for example, factory acceptance testing. If this is not possible, the purchase must be approved at a corporate level. As Colgate-Palmolive builds new factories, it works with the engineering teams that are designing the new factories to control noise as best as possible.

Equipment maintenance programs at Colgate also include a focus on controlling noise. For example, factory compressed air systems used to move small parts are a significant source (about 30 percent) of noise as well as energy consumption. Noise, energy, and maintenance teams have developed a guidance document to optimize system operation, minimize leaks, and provide guidance on appropriate use. Factories are replacing old, noisy, energy inefficient nozzles with new commercially available nozzles that are both quieter and energy efficient. Steps taken to reduce this noise have also reduced energy consumption leading to lower operating costs.

To improve staff capability on noise control, Colgate arranged live webinars for EOHS and engineering staff around the world. Noise control success stories at one factory are shared with staff at other factories. Topics addressed in the webinars include the fundamentals of sound propagation, principles of noise control, noise control options, and successful applications for specific equipment. In addition to webinars, a handbook has been developed and distributed to engineers and health and safety staff at each Colgate-Palmolive site. Topics covered in the noise reduction handbook include guidance on methods to identify noise sources, noise survey procedures, equipment specific noise controls, and noise reduction equipment vendors. Colgate-Palmolive is updating its intranet noise website and hearing conversation standards with new resources.

Each factory site is expected to propose annually at least two noise control projects for review and consideration at the corporate level. Three of the projects that were implemented during 2013 are described briefly below.

- A pet nutrition factory replaced, relocated, and enclosed a noisy blower. Noise levels near the blower were reduced from 119 dB(A) to 97 dB(A). This is a significant reduction for those employees who occasionally visited the space where the blower had been located.
- A site in Gebze, Turkey installed sound-absorbing ceiling tiles above a frequently occupied factory work area, reducing the noise exposure of 43 employees.

- Finally, in its largest plant, in Sanxiao, China, Colgate-Palmolive upgraded the safety guarding on an end-rounding machine with a combination of covers, seals, and insulation that reduced the noise level by 2 dB(A) and benefited 520 workers.

During 2013, more than 70 noise-reduction projects were implemented at 60 Colgate facilities around the globe. These changes reduced noise exposure for at least 2,000 employees. Downey expects similar numbers for 2014. As a result of these successful noise reduction programs, Colgate now has some manufacturing facilities in which hearing protection is no longer required. At its factory in Morristown, Tennessee, with more than 200 employees, none require hearing protection. Sites in Burlington, New Jersey, and Swidnica, Poland, have both met criteria to come out of mandatory use of hearing protectors.

NIOSH Citation[6]

Colgate-Palmolive was recognized for interventions such as: company-wide adoption of the NIOSH recommended 85-dBA threshold-limit value for 8-hour noise exposures; application of the 3-dB exchange rate for noise exposure assessments; adoption of inclusive criteria in their hearing loss prevention program; completion of multiple noise-control studies throughout each business unit to identify all noise sources affecting worker exposure; development and implementation of many pilot-program noise control measures; documentation of cost and noise reduction results; dissemination of an internal Colgate-Palmolive handbook on noise control; development of online, on-demand webcast training in noise control engineering available in six languages; establishment of checklists for sustaining low-noise levels; and the adoption of buy-quiet and design-quiet policies – even to the point of assisting equipment manufacturers in developing quieter machinery.

[6] http://www.cdc.gov/niosh/updates/upd-02-23-12.html

2.3 Getting the noise out—a multipronged approach to managing noise exposure in manufacturing

John Mulhausen, Director of Corporate Safety and Industrial Hygiene, 3M

3M is a $30-billion company with more than 87,000 employees and about 230 plants across the globe. These plants manufacture a wide range of 60,000 consumer and business-to-business products. John Mulhausen described 3M's strong corporate commitment to avoiding occupational safety and health risks for all employees, similar to the governance and support structure at Colgate-Palmolive, described in the previous paper in this chapter by John Downey.

Mulhausen listed the benefits that 3M receives by reducing noise levels at its plants (see Figure 2.3-1). Protecting employee hearing fits within the company's commitments to the environment and the community, which all, in a way, revolve around reducing waste. By reducing waste and increasing productivity, the company benefits and consumers see the firm in a positive light. For example, 3M has many pneumatic packaging operations and a lot of noise is generated when poorly designed air nozzles are used. Improving air nozzles reduces noises and also reduces the amount of compressed air, which can significantly reduce energy use in a factory. With these changes, 3M experiences real cost savings and benefits to the environment in terms of noise and greenhouse gas reductions.

Figure 2.3-1 *Why 3M is interested in reducing noise at its worldwide plants.*

Mulhausen is a fan of NIOSH's Hearing Loss Simulator.[7] It helps employees understand what it means to suffer noise-induced hearing loss. With the simulator, shop

[7] http://www.cdc.gov/niosh/mining/works/coversheet1820.html

floor employees as well as corporate executives experience how hearing impairment affects communications with other human beings. The simulator is a motivational tool that demonstrates future hearing loss outcomes and can be adjusted to an individual's audiogram results.

3M uses a three-pronged global approach to managing and reducing noise exposures at its plants (Figure 2.3-2). The three parts are: 1) high-quality noise measurements, analysis, and assessments, 2) use of sustainable controls to reduce noise exposures, and 3) an excellent hearing conservation program that is efficient and effective in exposure management.

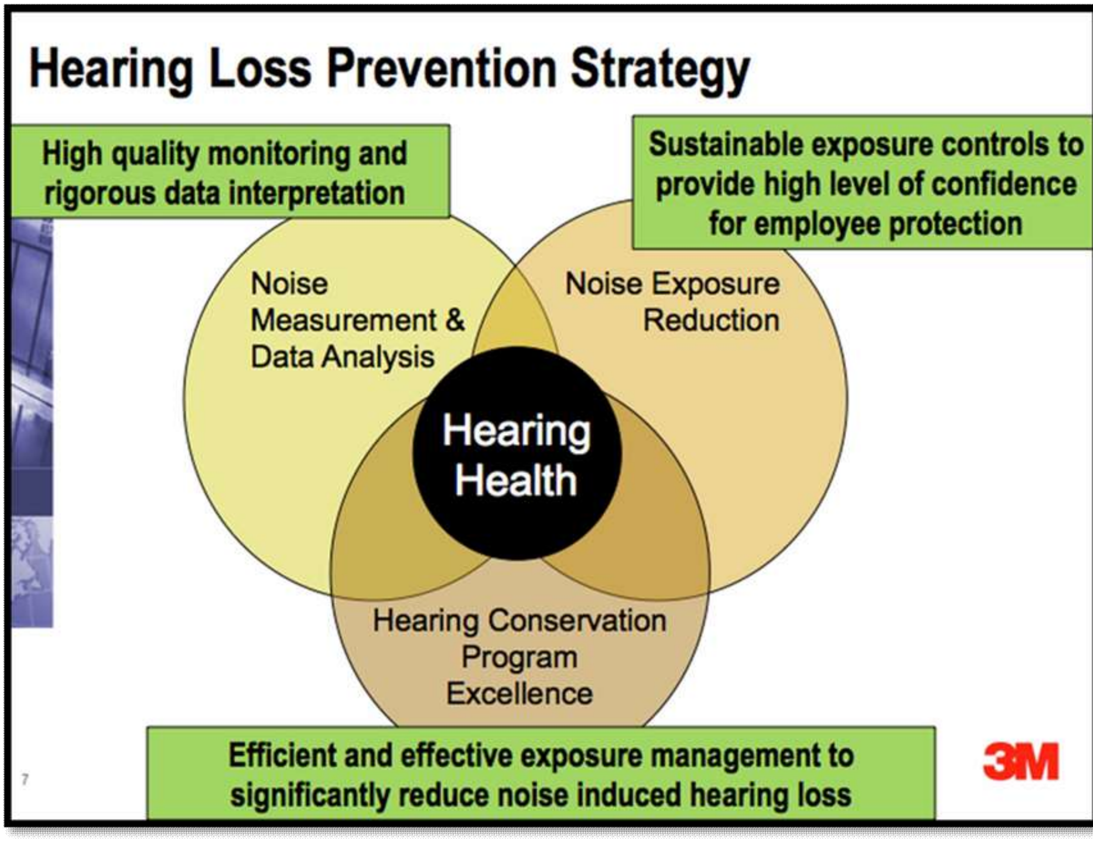


Figure 2.3-2 *A three-pronged strategy for hearing-loss prevention.*

The company places a strong emphasis on accurate and repeated noise exposure measurements and assessments that provide a good scientific basis supporting noise control decisions. If exposure is underestimated, employees face increased risk. If exposure is overestimated, the company faces unnecessary constraints for employees and production and unnecessary expenditures for engineering controls. Exposure assessment includes many noise dosimeter measurements together with a statistical analysis aimed at demonstrating with 90 percent confidence that employees' noise exposures are below the 85 dB(A) exposure limit during at least 95 percent of all worker-days.

The company has moved away from qualitative fitting of hearing protection to quantitative fit testing that meets the needs of individual employees. Training is provided to employees on an individual basis. Dan Westrum from the 3M Hutchinson Plant details this program later in this chapter.

Engineers and environmental health and safety personnel are educated about the importance of effective and sustainable noise controls to manage the risk of noise-induced hearing loss at 3M plants. Ongoing inspections and maintenance are necessary for noise controls to be effective over the long haul. Plants go through annual sustainable control planning activities to identify the areas where opportunities exist for improvements, for example, where many employees are exposed or new processes are taking place. They are moving away from installing new noisy equipment in already noisy areas where employees use hearing conservation just because employees are already protected acknowledging the increase risks of noise-induced hearing loss.

3M encourages facilities to think holistically about controls, using the Swiss cheese model of layers of protection (Figure 2.3-3). Wearing hearing protection alone or controlling noise alone is not enough. The best approach is some combination of the layers of protection, considering how they work together, and how they can be managed together to be most sustainable and to work well over time. Along with individually tailored hearing protection, employees need behavior-based training programs or feedback programs, routine audits and checks of hearing protection use, peer-to-peer programs, supervisor-to-employee programs, whatever needed. But even if hearing protection is in place, it is still important to be knocking down the noise levels, even if they are not reduced low enough to eliminate the need for a hearing conservation program.

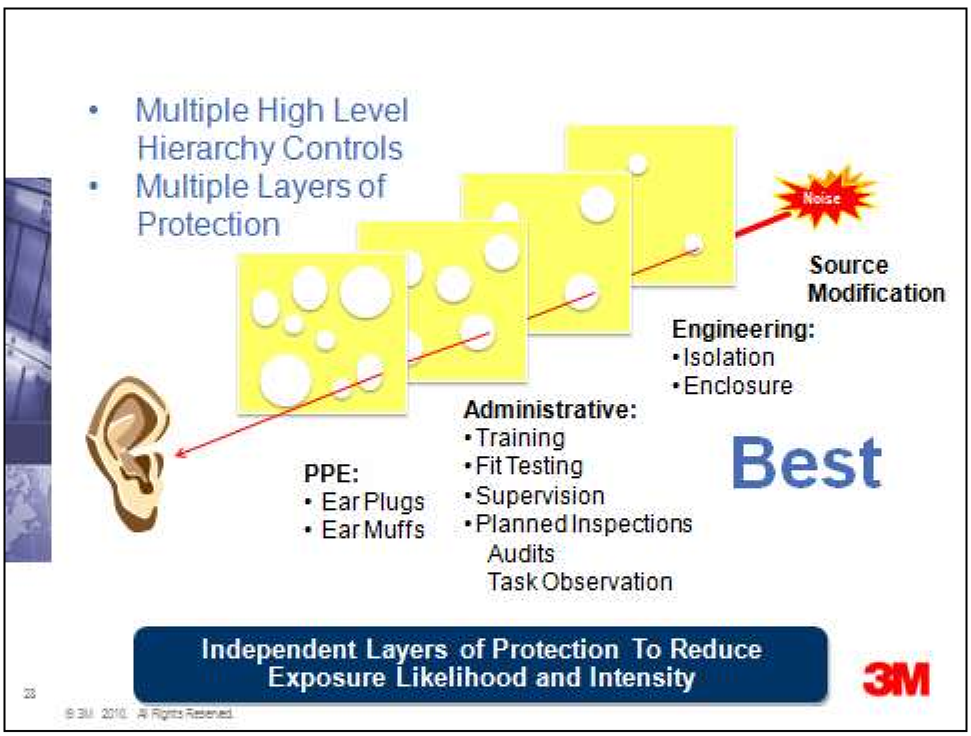


Figure 2.3-3 *Multiple layers of protection.*

Everyone in the company, including the plant manager, the manufacturing director, and the presidents need to understand why noise-induced hearing loss is important from a human point of view, an economic point of view, and for the environment and the company's reputation. It's a team effort. For hearing conservation and noise control to be effective requires both a top-down and a bottom-up approach at the plant and corporate levels. Plant managers need to be able to hold their ground and say, "No, we won't put more noisy equipment in this area, even if workers are already in a hearing conservation program." 3M has global engineering guidelines and training in noise control for corporate engineers and factory engineers. It also conducts annual noise control planning and prioritization for existing and new manufacturing and processes. Outside consultants are retained to assist. New projects are viewed as new opportunities to reduce noise. Figure 2.3-4 lists the noise control training and knowledge resources made available at 3M.

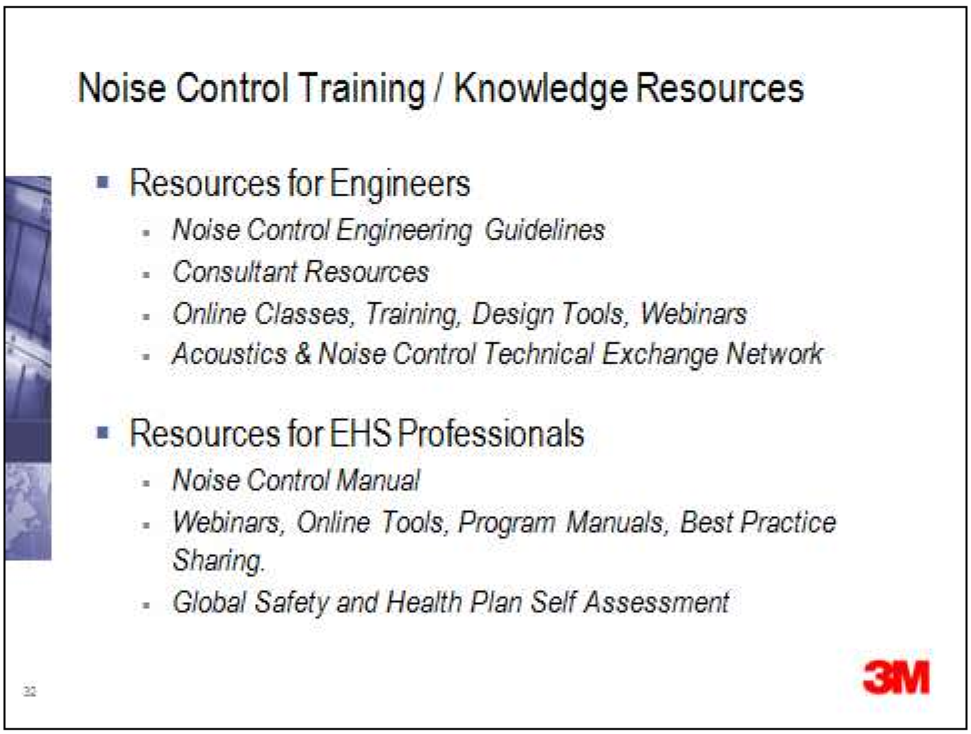


Figure 2.3-4 *Noise Control Training and Knowledge Resources Available at 3M.*

As a communications and incentive tool, 3M offers annual noise control awards for employees (best practice sharing) who submit projects that are reviewed by experts from across the country. The four award categories listed in Figure 2.3-5 are noise control innovations for: new equipment, existing equipment, inexpensive solution, and use of 3M products are listed in Figure 2.3-5. These recognitions drive a conversation across the company and have offered a successful mechanism for idea sharing.

Figure 2.3-5 *Annual Noise Control Awards for 3M Employees.*

2.4 Considerations for an effective hearing conservation program

Dan Westrum, Hutchinson Plant Industrial Hygienist, 3M Company

Recognized for its hearing conservation efforts, 3M's Hutchinson Plant received the 2012 NIOSH Safe-in-Sound Excellence in Hearing Loss Prevention Award (described in Chapter 2.1). Dan Westrum described some highlights of the plant's hearing conservation program. The plant, located in Hutchinson, Minnesota, has 1550 employees working in a 1.5 million sq. ft. manufacturing facility making a wide range of 3M products including pressure sensitive adhesive tapes, micro abrasives, coated and uncoated plastic films, and many products that go into other products. Approximately 600 employees at the plant are included in the plant hearing conservation program.

"The hearing conservation program at 3M Hutchinson was recognized for its all-inclusive and strongly integrated approach to worker hearing health including statistically driven noise exposure assessments, implementation of a Buy-Quiet program, and noise control for existing equipment," according to the NIOSH Safe-in-Sound Award website.[8] "In addition, it was recognized for comprehensive implementation of hearing protection fit-testing of all plant personnel, availability of both general and specialty hearing protection devices for off-the-job noise exposures (e.g. hunting and target shooting), high quality audiometric testing with professional supervision and evidence of strong support from corporate management, plant management and individual workers. This 3M program was tailored for individualized training and development of a culture of personal responsibility to maintain noise controls, identify noise hazards and properly fit and utilize hearing protectors throughout the facility."

The target for 3M's corporate Buy Quiet program for new equipment is not to exceed 85 dB(A) at nearby work areas. Westrum, however, aims for 75 dB(A) for new equipment to accommodate the cumulative noise from multiple machines. Some employees work extended daily shifts of 10 to 12 hours, and the goal is to improve the plant with lower overall noise levels. Westrum strives to help corporate management understand and support the hearing conservation, program, even during tight budgets.

3M has developed and implemented a hearing protector fit testing and validation program called E-A-Rfit™. The program includes audits, training and motivation for proper fit, and program management techniques for plant employees.[9]

During an early pilot test of 84 employees, nearly one-half were not using their foam ear plugs properly. After a few minutes of training or switching plugs, however, 98 percent of the employees were able to fit their plugs properly and achieve a Personal Attenuation Rating (PAR), or personal noise reduction, of 20 dB or better. Clearly, training can significantly improve use of hearing protectors and should reduce the number of employees that incur hearing loss. These results helped convince senior management and the plant operating committee to support the E-A-Rfit™ program.

As a part of this program, employees are told about the nine types of ear plugs available at the plant, the feel and softness of the different plugs, the pressure in the ear canal, how to insert the plugs for a best fit, and are told to insert a pair of test plugs. The test plugs have a narrow tube and small microphones that measure the noise from a

---

[8] http://www.safeinsound.us/winners.html

[9] http://www.E-A-Rfit.com

speaker both inside and outside the plug simultaneously. This provides a measure of the PAR[10] for that plug on the employee. If the measured PAR is less than 20, the employee reinserts the plugs to achieve a better fit or tries a different plug that better fits his or her ear canal. This program helps nearly all employees learn to use ear plugs properly. A few employees need custom-molded plugs to fit their canals.

A key value of the E-A-Rfit™ program is the one-on-one training received from experienced and knowledgeable instructors. New employees attend the E-A-Rfit™ program on the first day of orientation. Employees in the hearing conservation program attend every year. The program is not limited to employees in the hearing conservation program, however; employees not in the hearing conservation also attend training once every three years. 3M's goal is to provide the knowledge and skills to help all employees protect their hearing while at work and during off-work hours when performing noisy activities. It makes no sense to protect your hearing at work, and not to protect it at home.

The training also helps employees show their family members and friends how to protect their hearing. Employees are encouraged to take ear plugs home to protect their hearing while hunting or doing other noisy activities when away from work.

Westrum described the key elements to proper ear plug fit. It is important that users know how a good fit feels and sounds. Also important, of course, is that the worker has to care about and want to protect their hearing.

Westrum mentioned that 3M has used the NIOSH hearing loss simulator described in the Mulhausen paper above. The employee listens to sounds from a speaker simulating the experience with and without hearing loss. The differences are significant and help people understand the importance of hearing protection.

As part of a SafeStart program, 3M Hutchinson has recently begun interviewing veteran employees with significant hearing loss to learn about the difficulties they encounter and why they chose not to use hearing protection. One positive outcome is improved hearing protection for hunters, who typically don't want to wear hearing protection because they want to be able to hear the game and other natural sounds. The company store at the Hutchinson plant stocks and sells Combat Arms earplugs (a 3M product) that are said to include a proprietary technology allowing the user to hear ambient sounds while protecting against damaging impulse noise from firearms.

Westrum described the characteristics of different types of ear plugs. Polyurethane plugs (Neon, FX, EZ-Ins) feel softer to the touch, but exert more pressure inside canals than PVC plugs such as Classics. UltraFit plugs are pre-molded and resemble the shape of an evergreen tree. They tend to slip out after a while so they need to be reinserted a number of times during a shift, which may cause irritation. Plugs made of PVC do not absorb water while polyurethane plugs do absorb water, which can be a consideration when working in a hot, sweaty environment.

Because different people have different size and shape ear canals and different preferences—one size does not fit all—the Hutchinson plant makes available nine types of plugs for the employees to choose from. They include roll-down plugs and pre-molded

---

[10] **Personal Attenuation Rating (PAR)** is the amount of hearing protection achieved by the ear plug as actually worn by the individual.

plugs as well as polyurethane and PVC materials and outer canal muffs for employees who can't get a good fit from plugs.

NOISH Citation[11]

3M Hutchinson Plant in Minnesota, the largest 3M manufacturing plant in the U.S., is another recipient of the award. The hearing conservation program at 3M Hutchinson is recognized for its all-inclusive and strongly integrated approach to worker hearing health including statistically driven noise exposure assessments, implementation of a Buy-Quiet equipment program, and noise control for existing equipment. In addition, it was recognized for hearing protection fit-testing of all plant personnel, availability of both general and specialty hearing protection devices for off-the-job noise exposures (e.g. hunting and target shooting), high quality audiometric testing with professional supervision and evidence of strong support from corporate management, plant management and individual workers.

[11] http://www.cdc.gov/niosh/updates/upd-02-23-12.html

3
Best Practices: Noise Control in Manufacturing Industries

3.1 The calculation of sound levels in working areas as a planning tool for noise reduction

Wolfgang Probst, Managing Director, DataKustik GmbH, Germany

Predicting noise levels in industrial plants and other noise-relevant facilities is a valuable tool for ensuring the lowest possible noise levels within a given budget. Prediction methods are commonly applied before installing new facilities near residential areas. Gas turbine power plants, wind turbines, or other noise-relevant industrial facilities near residential areas are generally not planned and installed in developed countries before a prediction calculation has shown that maximal acceptable sound levels will not be exceeded. The same approach is possible in the interior industrial setting.

Predicting sound levels in an occupational setting is much more difficult than outdoor predictions because of the many reflections of sound in the room and the influence of room acoustical properties, for example:

- The distance between a workstation and the machine is often small relative to the size of the source,
- Machines and other equipment are often very complex noise sources,
- Workstations and radiating equipment are, in most cases, inside rooms, and full 3-dimensional calculations of many reflected sound contributions must be taken into account.

Probst described modeling software, called CadnaR[1], that is adapted to occupational noise. The figures and results presented in this chapter, and in greater detail in Appendix A, are based on use of the program.

To make the calculations, the characteristics of the source and the acoustical properties of the room must be taken into account separately. The noise source is characterized by it's A-weighted sound power level (e.g., the ISO 3740 series of international standards[2]), a simple measure of its directivity, and perhaps the emission sound pressure level (ISO 11200 series of international standards[3]) at one or more work stations. Next, the sound absorptive characteristics of the room are measured (ISO standard 14257[4]).

Using newly available software tools, experienced acoustical engineers can quantify important phenomena such as sound screening, absorption, scattering, and transmission through light-weight structures. Noise abatement measures can be included in the simulation to obtain the most economically advantageous solutions.

There are two fundamentally different approaches to calculate sound propagation inside rooms with many reflections influencing the sound pressure levels at receiver positions. The first method is based on sound rays. All possible ray paths from source to receiver must be

---

[1] http://www.datakustik.com/en/products/cadnar
[2] http://www.iso.org/iso/home/store/catalogue_tc/catalogue_detail.htm?csnumber=1260
[3] http://www.iso.org/iso/catalogue_detail.htm?csnumber=35377
[4] http://www.iso.org/iso/catalogue_detail.htm?csnumber=24014

constructed to get the final result. If a ray between source and receiver is reflected n-times, this is a reflection of n^{th} order. With the ray-based, or mirror-image method (Figure 3.1-1, sound attenuation by screening can easily be taken into account.

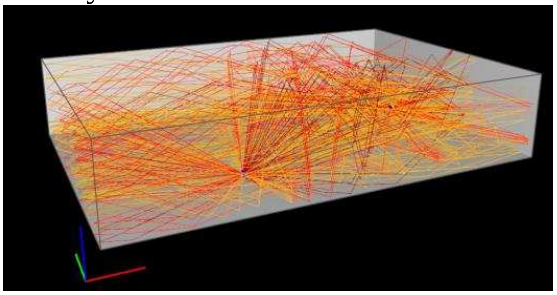


Figure 3.1-1 *Sound rays constructed with the mirror image method.*

The second approach, the particle method, represents the sound rays as "particles." Thousands or even millions of statistically distributed "sound-particles" are radiated in all directions from the sound source and follow a straight propagation line between the reflections at surfaces from the room or from other objects.

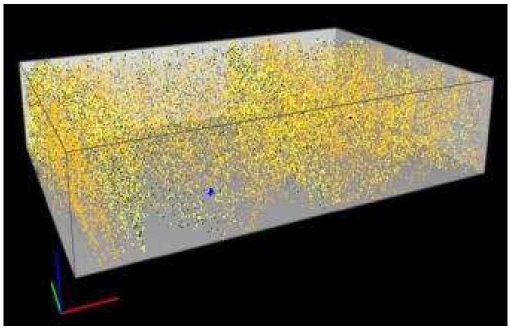


Figure 3.1-2 *A sound propagation simulated with the particle method.*

Modeling is the most important step in noise prediction for planned industrial plants with machinery. The layout with all geometrical and acoustical parameters relevant for the resulting noise levels must be transferred into a virtual model.

Small machines and devices (Figure 3.1-3) are simulated by a simple point source. Its location in the room is defined by coordinates *x*, *y*, and *z*, and the noise emission by the standardized values of sound power level and sound pressure level.

Figure 3.1-3 *A small machine, a press, radiating sound.*

Figure 3.1-4 *Filling machine in a bottling plant.*

A larger bottle-filling machine, shown in Figure 3.1-4 is enclosed in a light casing for safety reasons. In this case, sound is radiated from a larger surface and produces a sound field that cannot be simulated by a small point source. Figure 3.1-5 shows three examples for the simulation of larger box-type machines, such as the filling machine. The box can have any size and even be elevated to model sound particles propagating underneath.

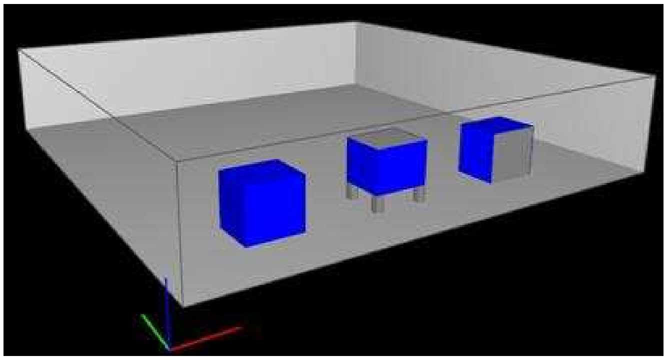


Figure 3.1-5 *Simulation of three box-type machines with different surfaces radiating sound.*

Figure 3.1-6 *Large washing machine in a bottling plant.*

With the combination of point sources, line sources and box-type structures, machines of any complexity can be modeled. Figure 3.1-6 shows a large bottle-washing machine in a bottling plant and Figure 3.1-7 shows, in a 3D-model of the washing machine area, how particles are emitted from the noise-relevant parts of the machine. The paths of the sound particles emitted from the noise-relevant machine parts are calculated taking into account that the massive body of the machine is acoustically opaque.

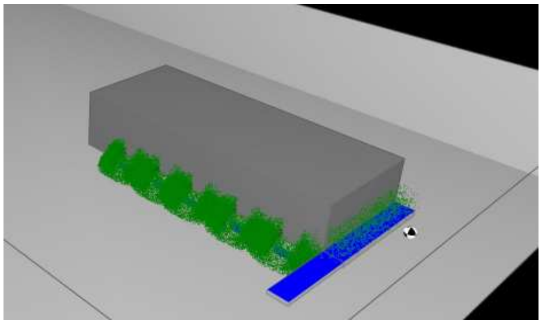


Figure 3.1-7 *Simulation shows how sound particles are emitted from bottle-washing machine.*

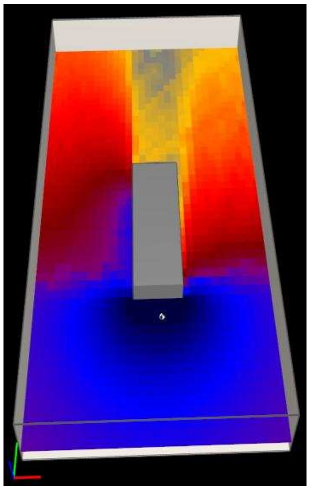


Figure 3.1-8 *Distribution of calculated sound pressure with absorptive walls* and ceilings.

The easy assembly of such machines from basic elements is an important property of simulation software used frequently for noise prediction. Figure 3.1-8 shows the distribution of calculated sound pressure levels with walls and ceiling completely absorptive, thus simulating free field propagation. The yellow color at the back of the massive machine indicates where noise levels are low due to the screening effect of the massive machine body. The main advantage of the method presented is the ability to integrate locally effective noise reduction measures, and to check their effect on receiver levels. For example, the simulation can test the effect of an optically transparent noise barrier around a workstation or an absorptive baffle system above the barrier to reduce the sound reflected by the ceiling.

The advantages of this software strategy become obvious when complete plants are modeled. The data structure of each machine, once created and saved in a library, can be treated as one single element. Then the library contains descriptions of the noise level caused by each machine separately. This structure facilitates the otherwise extremely time consuming development of necessary noise reduction measures to reach the defined target levels, for example 85 dB(A) at workstations.

In the future, a manufacturer can offer a valuable customer service by providing a software model of its machine, which can be plugged into a software model of the room into which the machine is installed. Then noise declaration is basically included in the model, and no separate declaration is required.

During the last decade, many measurements have been performed to obtain reliable data to check the accuracy of the calculation methods. One such set of measurements was obtained by placing a transportable screen in different environments inside empty and fitted industry halls, and to measure the sound levels at different distances behind the screen. A dodecahedron loudspeaker produced well-defined sound emission in each frequency band at the opposite side of the screen. In another case, sound levels produced by a well-defined source in 122 industrial halls were measured at receiver positions distributed along a straight line.

Some typical results show that actual measurements were very close to calculations made in the simulation. (Figure 3.1-9). It is obvious that the particle model applied to calculate sound propagation is well suited to represent the different acoustical properties of the room. The particle-method was also well suited to calculate sound propagation in a room with various types of equipment installed.

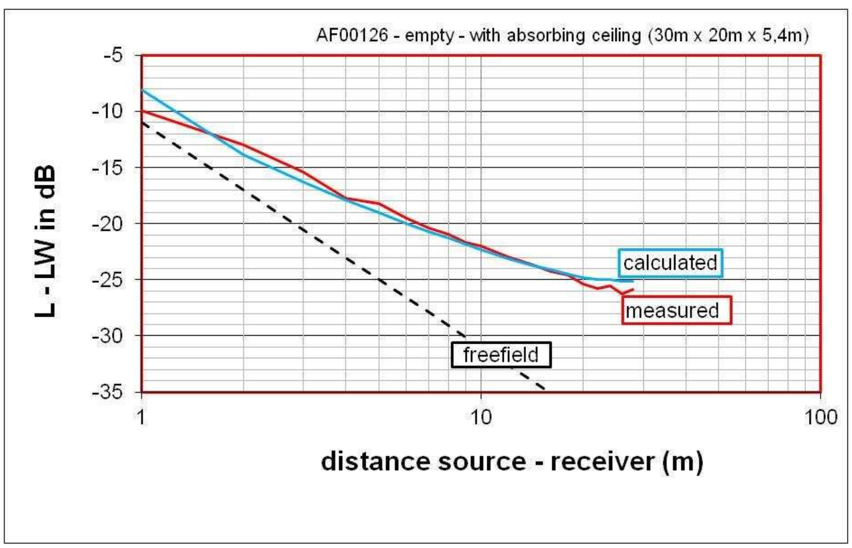


Figure 3.1-9 *Comparison of calculated and measured levels relative to* L_w *with the room empty, but with a sound-absorptive ceiling.*

3.2 The physics of low noise design

David Herrin, Mechanical Engineering Department, University of Kentucky

David Herrin, a professor of mechanical engineering from the University of Kentucky, proposed using a systems approach to designing low-noise equipment and machinery. He reviewed the Source-Path-Receiver Model first proposed by Bolt and Ingard in 1957.[5] The model offers a helpful start to identifying opportunities for controlling noise at the source of the noise, interfering with its transmission or energy path, and/or changing the characteristics of the receiver (Figure 3.2-1).

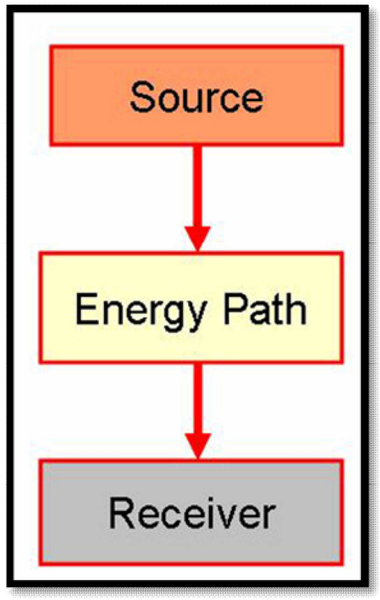


Figure 3.2.1. *Establishing a causal chain for noise..*

Using the model helps with step one of four organizing steps: clarification of tasks, conceptual design, detailed design, and finally, prototyping. Detailed descriptions of much of this work can be found in the International Organization for Standardization (ISO) technical reports TR 11688:1[6] and TR 11688:2[7] and M. Bockhoff's chapter in the "Handbook of Noise and Vibration Control[8]."

A forklift, for example, has several noise sources, including the internal combustion engine, the intake exhaust, and the cooling fan, as well as the transmission, the chain and hydraulics (Figure 3.2-2).

[5] Bolt, R.H. and K.U. Ingard. 1957. System Considerations in Noise Control Problems. Page 22-1 in Handbook of Noise Control, First Edition, edited by C.M. Harris. New York: McGraw-Hill.
[6] International Organization for Standardization. 1995. Acoustics: Recommended Practice for the Design of Low-Noise Machinery and Equipment-- Part 1: Planning (ISO/TR 11688-1).
[7] International Organization for Standardization 1998. Acoustics: Recommended Practice for the Design of Low-Noise Machinery and Equipment-- Part 2: Introduction to the Physics of Low-Noise Design (ISO/TR 11688-2).
[8] Bockhoff, M. 2007. Design of Low-Noise Machinery. Chapter 66 in Handbook of Noise and Vibration Control, ed. M.J. Crocker. Wiley, Hoboken, NJ. ISBN: 978-0-471-39599-7. Bockhoff, M. 2007

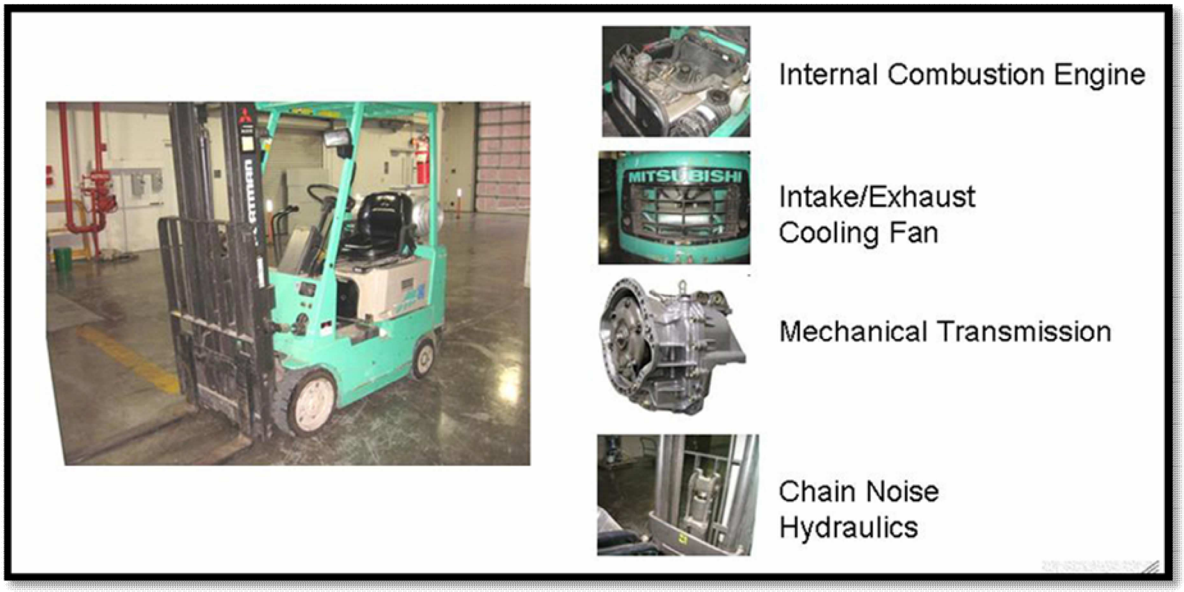


Figure 3.2-2 *Relevant noise sources in a forklift truck.*

The original source-path-receiver model had a rather simple description of the source, whereas multiple sources and transmission paths exist within the forklift before being radiated from the forklift to the receiver. Therefore, it is appropriate to adopt a more complex model that involves an intermediate energy concept called "energy conduit." The conduit involves transmission within the source to, for example, various vibrating surfaces. The first half of the more complex model is in Figure 3.2-3A; the second half is in Figure 3.2-3B.

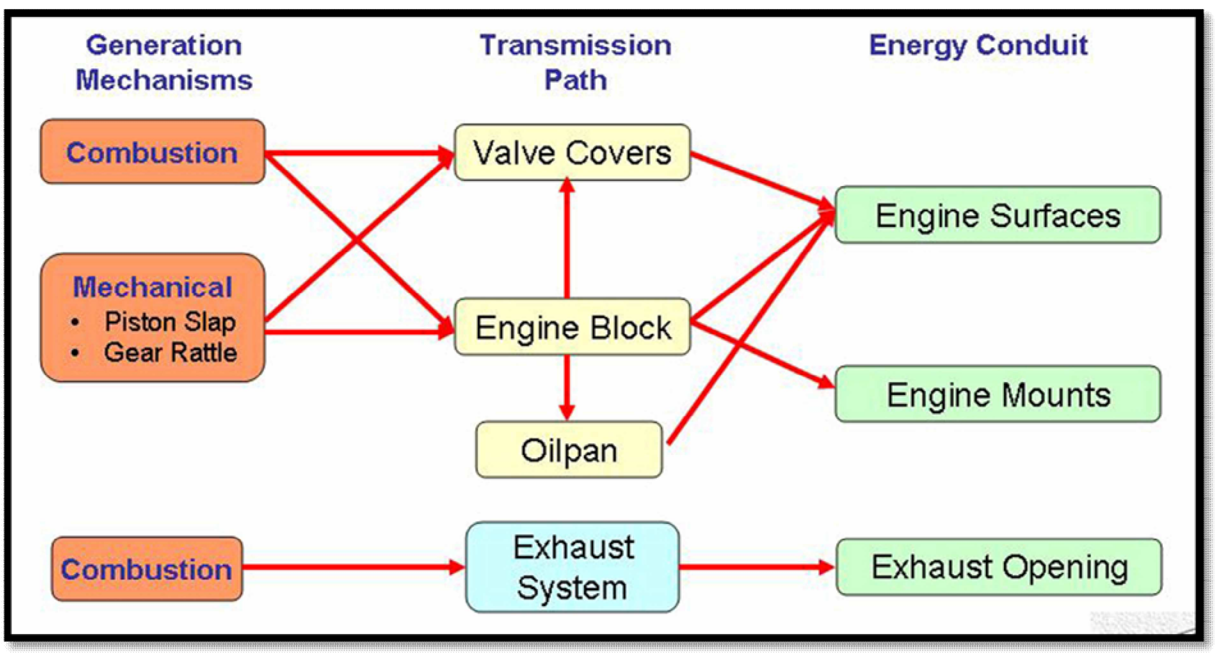


Figure 3.2-3A *Source energy paths.*

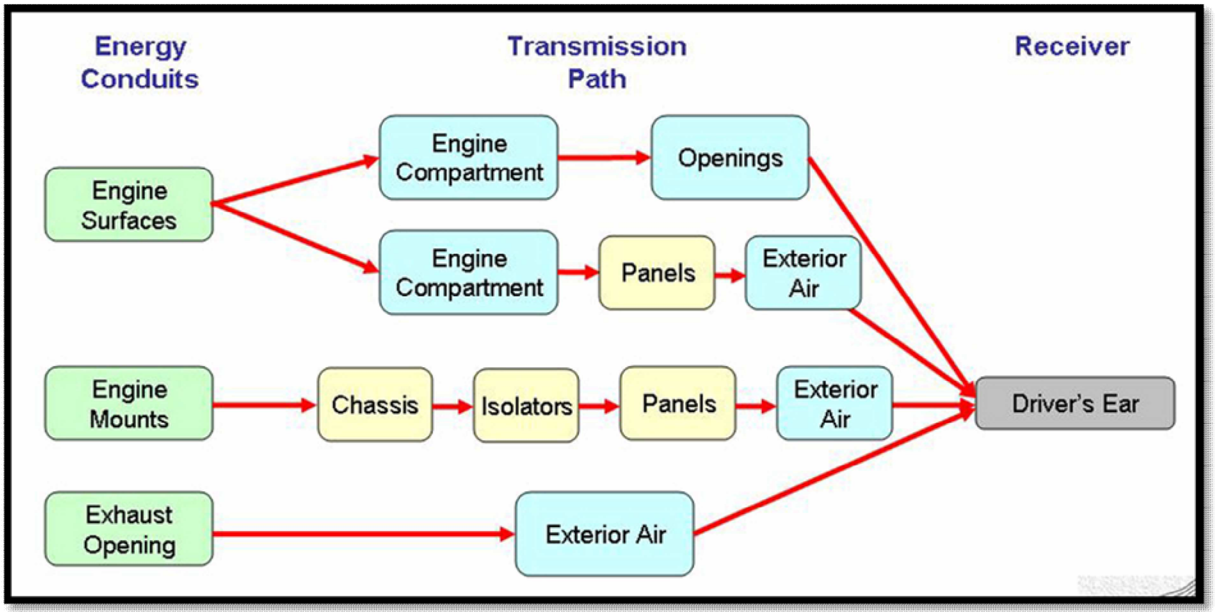


Figure 3.2-3B *Receiver energy paths.*

In this case, the receiver is the driver's ear, and it is not a simple matter to develop a quantitative description of the importance of each path to the sound pressure level at the operator's ear. One assumption made by N. Ivanov[9,10] is that the sound pressures from the different paths are incoherent; that is, the time-averaged product of the sound pressures from any two paths equals zero. This means that the mean square pressures from over each path (p_1, p_2, p_3…. can be added to obtain the total mean square pressure, p_t^2:

$$p_t^2 = p_1^2 + p_2^2 + p_3^2 \ldots.$$

Ivanov also made a number of other assumptions in his analysis:

- Sound sources are incoherent, the acoustic signals are wide band
- Sound fields in closed-spaces are quasi-diffuse
- Impedances of enclosure surfaces are approximately equal
- Resonance phenomena in closed spaces are ignored as a rule
- Sound sources generate sound fields which may be idealized as spherical, cylindrical or plane wave
- Sound sources in closed spaces consist of omni-directional radiators
- Sound pressure at a specific point is determined by the energy summation principle
- Sound waves near a reflecting surface are considered at a specific point to result from summation of waves from the primary and mirrored sources
- Closed spaces are characterized by an average coefficient of sound absorption
- Sound power of the source does not depend on the characteristics of the closed space

[9] Crocker M.J. and Ivanov N. ed. 1993. Noise and Vibration Control in Vehicles. Politekhnika, St. Petersurg.

[10] Ivanov N. and Copley D. 2007. Noise and Vibration in Off-Road Vehicle Interiors – Prediction and Control, Chapter 98, Handbook of Noise and Vibration Control, ed. M. J. Crocker, Wiley, Hoboken, New Jersey.

- Experimental corrections are introduced into sound pressure level values for frequencies less than the quasi-diffuse limit
- Near sound field is corrected by a coefficient χ
- Sound field diffusivity violation is estimated by a coefficient ψ
- Distribution of vehicle frame vibration is assumed to disregard dissipation losses
- Ratio of the maximum to the minimum linear dimensions of acoustic spaces does not exceed 5
- All elements of noise protection structures (walls, openings, slots, holes, etc.) are represented as elementary radiators
- Noise protection structures are considered to consist of a number of elementary incoherent radiators

Ivanov also suggested several factors that influence the sound pressure at the receiver produced by transmission over the various paths. These include:

- Direct radiation from the source
- Source-receiver distance
- Directivity
- The solid angle into which the sound radiates
- The effects of the near field of the source
- Diffusity of the sound field

Some general rules have been developed[11] for low-noise design (Figures 3.2-4A and 3.2-4B), for example, installing acoustic enclosures, silencers, damping screens, and vibration isolation, as appropriate.

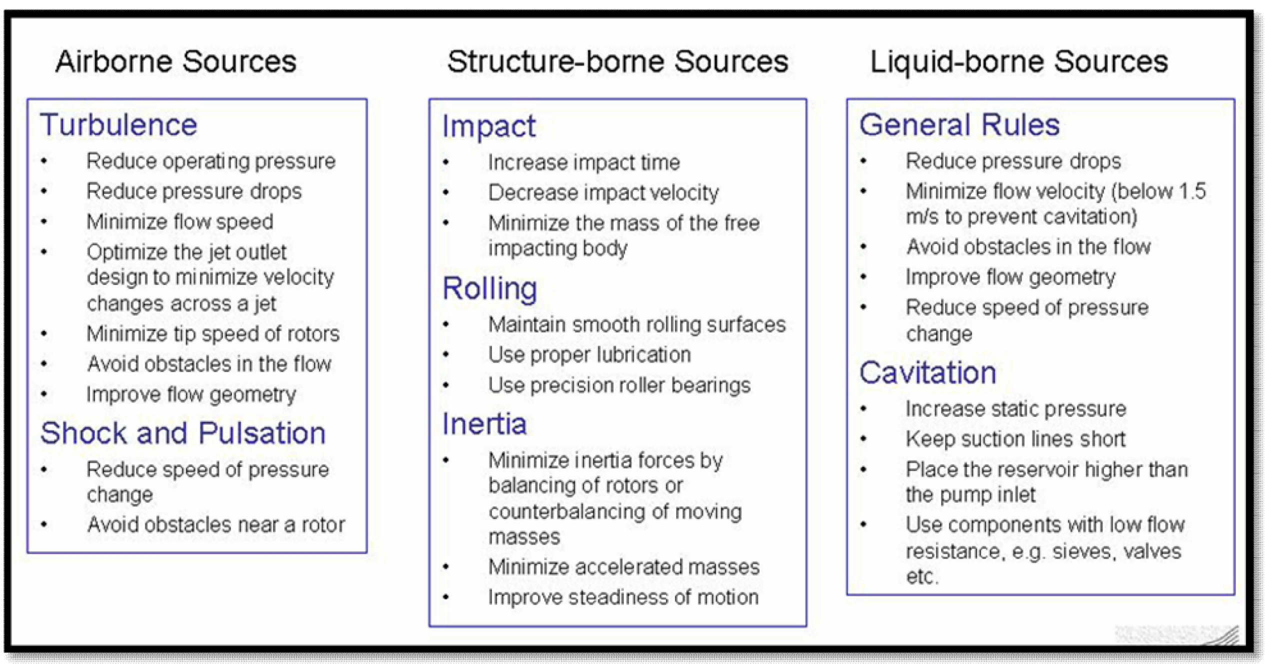


***Figure 3.2-4A** Design rules for sources of noise.*

[11] ISO/TR 11688-2: 1998, Introduction to the physics of low-noise design. International Organization for Standardization (ISO), Geneva.

Acoustic enclosures

- Enclose noise sources totally, even small gaps or holes are important
- Use solid sheets for the outer shell of the enclosure
- Use absorbent material inside
- Use silencers at openings for ventilation, cables, pipes, transport of material etc.
- Avoid rigid connections between enclosure and machine
- Minimize number of mounting points
- Enclosure of components can be effective

Screens

- Use solid sheets (sound insulating material) for the screen
- Use screens for operator positions
- The side of the screen facing the machine should be supplied with a sound-absorbent cover

Silencers

- Use absorption silencers for broad band noise
- Avoid velocities of flowing medium greater than 20 m/s in absorption silencers
- Use reflection type silencers for low frequency noise
- Use pneumatic expansion silencers for compressed air outlets

Vibration Isolation

- Use elements or layers which are sufficiently resilient
- Apply a sufficiently stiff and heavy foundation

Damping

- Apply damping for reduction of transmission in the resonant response range
- Apply damping near the source
- Consider additional damping for thin plates

***Figure 3.2-4B** Design rules for the path of the noise(from footnote 11).*

A 1982 book published by Brüel and Kjær[12] contains information on low-noise design. Two examples are shown in Figure 3.2-5 below.

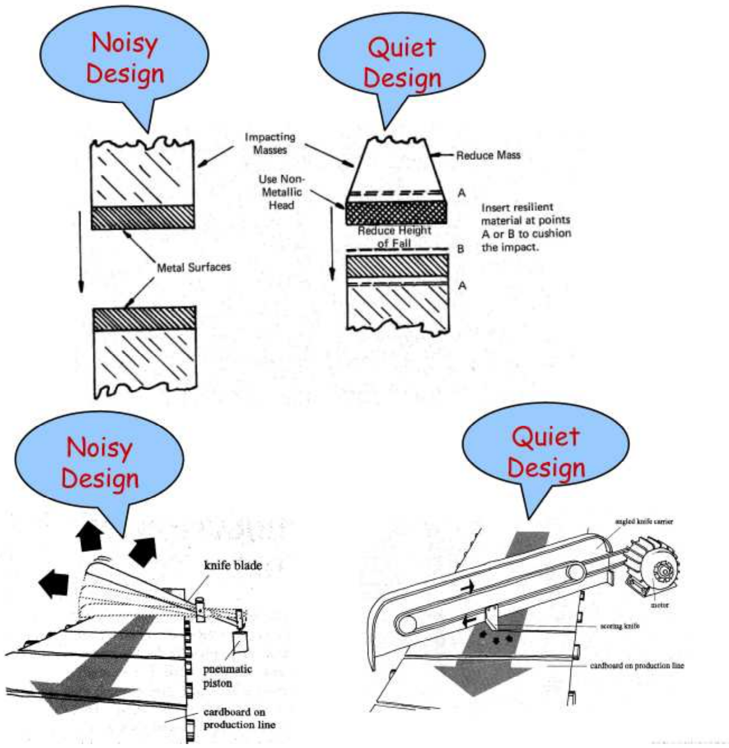


***Figure 3.2-5** Two examples of low-noise design.*

[12] Brüel & Kjær. 1982. Noise Control Principles and Practice. Denmark. ISBN: 978-8787355421

** Post workshop note: Many other examples of low-noise design have been published in *Noise/News International* and later collected into a booklet titled Noise and Vibration Control: Principles and Applications, which was published by Ingemansson AB and is available from the INCE Foundation.

3.3 Noise reduction process

James K. Thompson, Branch Chief, Hearing Loss Prevention, Office of Mine Safety and Health Research, National Institute for Occupation Safety and Health

James Thompson described the noise reduction process developed by NIOSH's Office of Mine Safety and Health Research in Pittsburgh. He also shared several examples of its application.

NIOSH has used this model process for 5 years with success. The process has helped NIOSH organize its noise-control efforts and evaluate performance. It has allowed the Office to set clear goals for performance, cost, and applicability, and to obtain stakeholder buy-in, solve the right problem, provide clear goals and minimize trials, provide workable solutions, and focus on long-term durability and performance.

The process begins with a needs assessment, followed by development of the controls and then a short trial to determine the effectiveness of the controls. Once effectiveness is demonstrated, technology transfer begins. A long-term effectiveness study also takes place, looking at noise performance, durability, maintenance needs, and other issues.

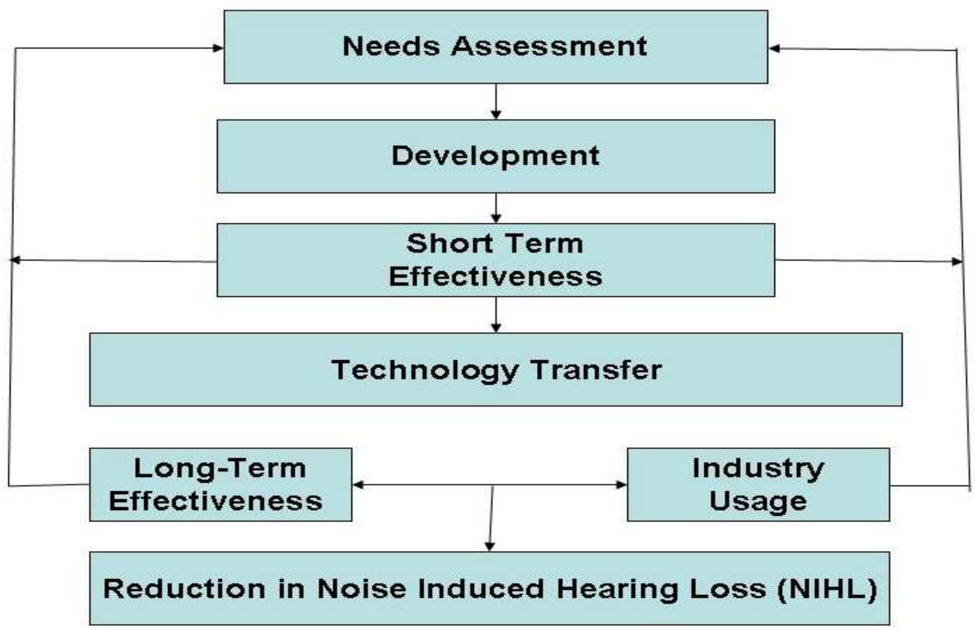


Figure 3.3-1 *Flow chart of the development process*

The six stages of the noise reduction process are iterative and each step requires a strong feedback loop involving stakeholder groups. The needs assessment begins with surveillance data and input from all stakeholders: users, maintenance department, equipment manufacturers, health and safety department, employee unions, and perhaps others. The aim is to determine: What is the problem? And how bad is it? Problem definition is critical and may require dosimeter and time/motion studies. However input must go beyond noise or exposure issues to include input on operational issues, including maintenance and other considerations.

Once needs are assessed, development of controls can begin. Solutions may be simple, such as a selection of the proper silencer, or complex, involving elaborate measurements, modeling, and machine modifications. Again, stakeholder input is essential. How is the equipment used? What does the operator look for? There may be a compromise among noise controls, usage preferences, maintenance issues, etc. The outcome of this step is a solution ready for short-term effectiveness evaluation.

The short-term effectiveness test of a solution is carried out in the field at an actual installation, and can take a week to several months. Sometimes the short-term effectiveness test will point out unexpected issues. For example, a collapsible drill steel enclosure was designed to reduce the noise of a roof bolting machine by 8 dB (from 102 dB to 94 dB). But when the enclosure was put in place, it prevented machine operators from visually inspecting the drill steel to determine if proper thrust was being applied. Operators refused to use the enclosure. In this case, the testing led to a start over.

Once an effective solution exists, technology transfer, the most difficult part of the process, takes place. It requires stakeholders to own the solution. NIOSH does not manufacture noise controls, so it works with partners to implement the actual noise control, during the technology transfer stage. The desired outcome is a vendor commercializing the control so that it can be widely used. Technology transfer worked effectively to reduce noise in the Continuous Mining Machine, which is used in underground coal mining worldwide. In the United States, 1,100 machines are in use. By replacing the conveyor chain, noise was reduced by 3 decibels, according to short-term effectiveness studies. The manufacturer redesigned the conveyor chain, making the quieter option the standard version offered. Today, close to 40 percent of the market has the new chains in place.

Once the parts are in place, the long-term effectiveness studies can begin and NIOSH works with stakeholders to facilitate widespread industry usage. Long-term effectiveness criteria may ask: does the noise control continue to be effective over time? Does the control degrade over time? Does it need to be replaced before scheduled maintenance? Having this information and disseminating it to potential users is critical.

To protect the population of miners, the controls developed through NIOSH must be widely adopted and commercially available. NIOSH also monitors the use of controls and collects information on how they perform. Lessons learned may provide feedback for additional refinements. Long-term assessment is crucial. We have also seen good controls no longer working or becoming source of annoyance in the field. The final stage in any noise control program is to be able to assess the impact and this can only be done in the long term.

The noise reduction process allows planners to define specific metrics to assess performance. The environment in which mining machinery operates can be difficult to define. Choosing the appropriate metrics for the situation gives the approach important flexibility. If one metric does not appear to be achieving results, another can be selected. Some examples are in Table 3.4-1.

Table 3.3-1 Examples of choosing the appropriate metric for a situation

Process	Metric example	Data source
Needs assessment	High exposure related to machine	Exposure surveillance system
Development	3 dB(A) reduction	Sound power measurements in lab
Short term effectiveness	Reduce worker exposure	Field dosimetry and OAEs
Technology transfer	Control is readily available	Manufactured and sold
Industry usage	In use in all regions	MSHA district managers
Long term effectiveness	Reduction maintained for life of product	Field dosimetry and OAEs
Reduction in NIHL	NIHL reduction in affected commodities	Audiometric surveillance

With this model, NIOSH's Office of Mine Safety and Health Research has successfully implemented several noise controls that are now commonly used in the mining industry. In part this is due to adherence to this process. This carefully defined noise control process could be adopted for many industrial situations outside the mining industry.

3.4 American National Standards for noise emission measurements

William J. Murphy, Hearing Loss Prevention Team, National Institute for Occupational Safety and Health

William Murphy is co-leader of the Hearing Loss Prevention Team in the NIOSH Division of Applied Research and Technology in Cincinnati. He provided a two-part summary on noise standards,[13] first discussing American National Standards Institute (ANSI) standards for sound power determination and then how to use sound power standards for product labeling.

The Structure of the American National Standards Program

The Acoustical Society of America manages the American National Standards Institute (ANSI) standards program for the following committees, S1 for Acoustics, S2 for Vibration, S3 for Bioacoustics and S12 for Noise. Susan Blaeser is the Manager of the ASA's standards efforts,[14] the Director for Standards is Paul Schomer. Rich Peppin is the chair of S1, Ali Herfat is the chair of S2 for Vibration standards, Chris Struck is the chair of S3 and William J. Murphy is chair of S12 for Noise. Under these committees, the United States has opportunities to participate in the International Organization for Standardization (ISO). The United States has one vote on international standards which requires more cooperation if important issues are going to be settled. The official representatives to the ISO Technical Committees are Walter Madigosky for TC 108, and Paul Schomer for TC 43 and TC 43 Subcommittee SC1. American National Standards for the determination of noise emissions of equipment are developed by S12. Descriptions of these standards may be found on the Internet.[15] Maling[16] has listed the international noise emission standards.

Standards for the Determination of Noise Emissions

When determining sound power, three different room designs are described in the standards: *anechoic* (meaning free from echo), *hemi-anechoic*, and *reverberant*.

A typical *anechoic* room is rectangular and has wedges on the six interior walls and a mesh trampoline to permit positioning the device being tested in the center of the volume of the room. In a *hemi-anechoic* room the floor is a reflective surface meant to simulate what might happen during outdoor measurements, in quiet without any reflections except for the ground. A *reverberant* room is designed to be highly reflective with non-parallel walls and diffusers on the walls to prevent the development of standing wave modes that are characteristic of rectangular rooms.

For measuring in the three types of rooms, several measurement methods exist. Perhaps the most common is the *pressure-over-area* method. In this configuration, a set of microphones sample the sound level at a prescribed distance from the source outside of the near field of the device under test (see Figure 3.4-1). The microphones are distributed over an imaginary surface that encompasses the device under test (DUT), and the pressure over a given area is used to determine that average power output of the DUT. The pressure over area method requires that

[13] Please note that the opinions presented in this talk are his own and should not be interpreted as any official policy of the Centers for Disease Control and Prevention, the National Institute for Occupational Safety and Health or the US Environmental Protection Agency. Any products mentioned in this paper are not endorsed or promoted by NIOSH, CDC or EPA.

[14] The names in this paragraph were current at the time the workshop was held.

[15] http://acousticalsociety.org/standards/ansi/s12

[16] Maling, G.C. Jr., International standards for specifying noise emissions, *Sound&Vibration*, **47**(12), 13-16, December, 2013.

the noise be coming from the source and that there not be other sources which are acting as sources outside the imaginary volume.

For instance ANSI S12.55 is used to measure sound power in fully anechoic spaces and in hemi-anechoic spaces. ANSI S12.54 and S12.56 are used in hemi-anechoic environments, and ANSI S12.51 and S12.53 are used to determine sound power in reverberant environments. The different standards reflect varying degrees of precision involved in conducting the measurements. The NIOSH sound power laboratories in Pittsburgh and Cincinnati conduct measurements at the Engineering grade, ±2 dB. To achieve Precision grade, ±1 dB, requires greater control of temperature and humidity.

Figure 3.4-1 *An IBM server surrounded by microphones at the IBM Acoustics Laboratory, Poughkeepsie, New York.*

In the *substitution,* or *comparison, method,* a calibrated reference sound source is tested in the space to establish the room constant and understand how the sound might be absorbed by the space. The substitution or comparison method can be conducted in just about any space, the most satisfactory being a *reverberation room.* The sound absorptive characteristics of the space affects the sustained sound pressure level of the reference sound source when it produces a continuous noise in the room.

The sound source is tested in the room with the other equipment turned off. The device of interest is turned on and the sound source is turned off. The sustained level in the room while the device under test (DUT) is running is a function of the sound power of the DUT and the room constant. By measuring the room constant with a known source, the sound power can be determined.

More sound absorption equates to less build up of sound energy in the space. Once the reference sound source has been measured, the microphones are kept in the same position and the DUT is operated and assessed. From the two measurements, the sound power of the DUT can be determined. When a product is purchased that has a Noise Declaration provided, the validity of that declaration can be tested after the product has been installed.

Finally, the *sound intensity method* is best suited for *in situ* sound power measurement because it can be performed in any environment. It relies upon making measurements over a measurement surface enclosing the DUT with a pair of phase- and amplitude-matched microphones. The sound intensity is determined as the product of the average pressure of the point between the microphones and the derived particle velocity estimated by the difference between the microphones.

Why Measure Sound Power?

There are several reasons for measuring sound power. Sound power is an inherent property of the device under test. The sound pressure is affected by the room acoustics—the absorptive effects of the ceiling tiles, the panels on the wall, the number of people in the room, and the location of the listener relative to the device under test. That's the difference between sound pressure and sound power.

With sound power, it is possible to develop acoustic models that can be used to predict the noise levels in various environments. Using the geometry of the room, the sound power of various sources, the absorption coefficients of the surfaces in the room, accurate models[17] can be developed to predict the distributions of sound in the room.

Sound pressure, on the other hand, does not permit modeling in a generalized manner. Sound power is an inherent quantity of the source, precisely the quantity that should be used when attempting to provide informative labeling for noise emissions.

In summary:

- Sound power is an inherent property of the source
- It can be used to develop acoustic models of noise distributions and noise exposures
- Sound pressure levels depend on:
    - Room acoustics
    - Receiver distance from the source
    - Receiver orientation to the source
- Sound power is the appropriate metric for labeling

How Might Noise Emission Labels Be Implemented?

Matt Nobile from the IBM Hudson Valley Acoustics Laboratory in Poughkeepsie, New York has been working on developing labeling standards for products. In a presentation at the National Institute for Occupational Safety and Health in November 2011, Nobile presented some concepts that could lead to standardized declarations for a variety of products (Figure 3.4-2).

On the left of Figure 3.4-2 is the *comparative declaration label*. The unit associated with the product noise rating (PNR) is the decibel, but the unit is notably absent. In a way, this is a concession to the lack of the public's understanding of decibels and their meaning. PNR is the product noise rating (its scale ranges from 0 to 120). The Red Arrow in the Figure 3.4-2 example identifies the product noise rating, 90 in this case. The blue bar on the scale indicates how this product compares to a range of similar products. Along the left of the image are icons of speakers indicating soft, low-level sounds ranging to loud high-level sounds. On the right in the box is a numerical expression of the range of other similar products. In this case, the range is 88 to 109, indicating that this product, at 90 dB, is near the bottom of the range of similar products.

[17] See the paper by W. Probst elsewhere in this report.

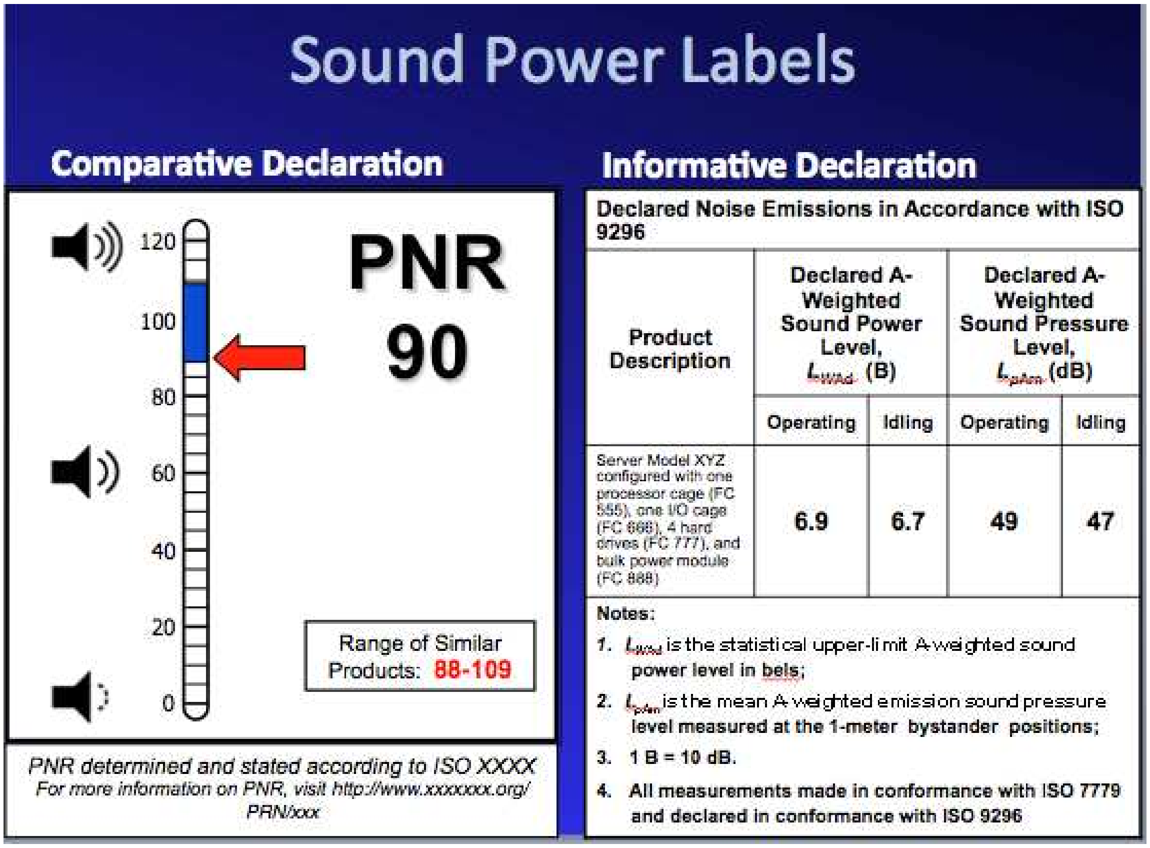


Figure 3.4-2 Noise emission labels.

On the right of Figure 3.4-2 is an *informative declaration label*, which gives the numerical performance of the product according to a specific international standard (ISO 9296). The numbers on the left half are sound power in bels[18] (1 bel = 10 decibels) for the product when it is operating and when it is idling. The numbers on the right half are the sound pressure level when the product is operating and when it is idling. For assessing the risk of noise-induced hearing loss, an industrial hygienist will need to know the level at the ear where a worker might be positioned. Additional information could be included with the informative declaration. That is, the sound power spectrum could be included in secondary information. The spectrum is critical to determining risks. Sound with content in the 2000 to 6000 Hz range can present an increased risk compared to that at lower frequencies.

Labeling can help consumers make purchasing decisions. Figure 3.4-3 shows sound power levels for a common household appliance, a dishwasher, plotted against the manufacturer's suggested retail price. It demonstrates that quiet can be a marketing tool to sell products. If you want a dishwasher that is 40 dB(A), you will pay upwards of $1,600. Louder machines will cost less. Consumers can understand a noise rating. They can understand that quieter equipment will not impair their ability to interact with others or to have a conversation.

---

[18] The unit *bel* has been introduced internationally as the unit of sound power level to distinguish it from sound pressure level for which the unit is the decibel. The bel has not been widely accepted, especially in the USA, and the decibel (with A-frequency weighting) is commonly used as the unit of both sound power level and sound pressure level. Thus, the quantity being specified (sound pressure or sound power) must be indicated in the text.

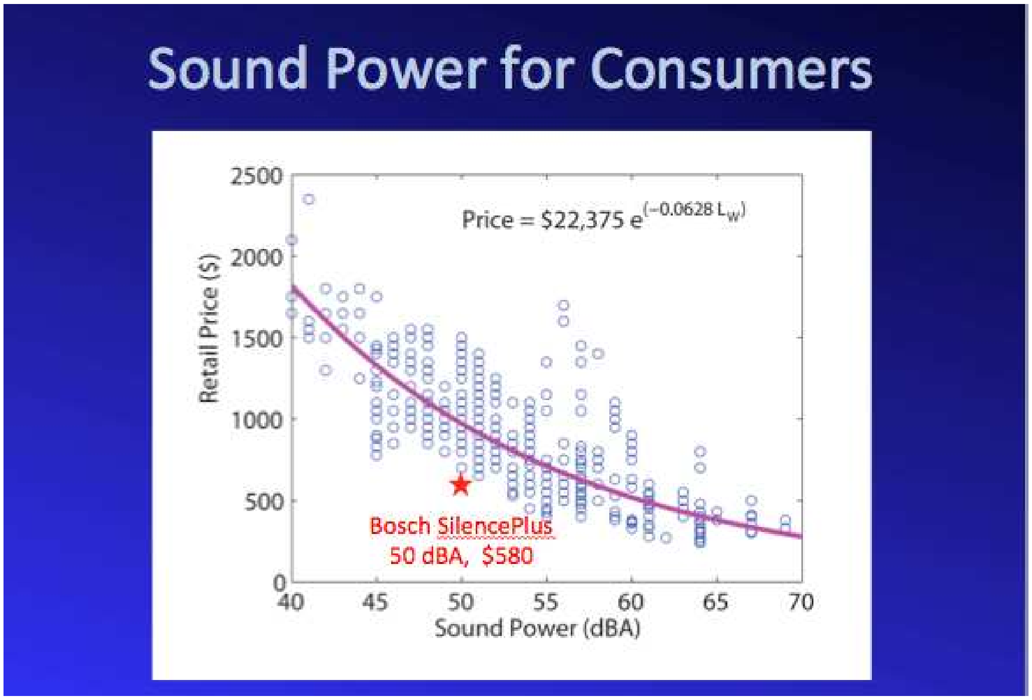


Figure 3.4-3 *As sound power goes down, price goes up.*

Murphy ended with a call to action. The public doesn't need a lot of education to interpret the numbers on the labels discussed in this paper. The labeling just needs to be put in place. In the United States, table saws don't necessarily come with noise ratings, but they could.

If we are going to reduce noise in the manufacturing environment, companies need to be aware that the product noise rating is a method through which noise emissions of competitive products can be compared. A manufacturer can publish noise emission declarations. With noise emission data measured according to national or international standards, consumers can verify that equipment is operating within its declared boundaries. Standards for the determination of sound power are available. What is needed is a widely accepted method for labeling the noise emissions of products.

3.5 A brief introduction to "Buy-Quiet" programs

George C. Maling, Jr., Managing Director Emeritus, Institute of Noise Control Engineering of the USA (INCE-USA)

"Buy-Quiet" programs offer a systematic method for the purchase of low-noise machines. A manufacturer makes a declaration of the noise emissions of a machine and the operating conditions associated with the declaration. A purchaser includes a requirement on the noise emissions of the machine, and there can be negotiations between the two parties, which ideally lead to the purchaser obtaining a machine with the lowest noise emissions considering the state of noise control technology.

In 1998, NIOSH recommended that companies adopt Buy-Quiet policies for new equipment acquisitions[19,20,21,22] Haag[23] describes a four-part process that management can implement to have an effective buy-quiet policy. The process includes selecting products or operations to be targeted for noise reduction through new purchases, setting criteria for new equipment noise levels, requesting noise level specifications from manufacturers, and including these noise level data in bid evaluations. Input from workers should be incorporated into the buying process.

In 2011, NIOSH held a Buy-Quiet workshop to determine feasibility and functionality of Buy-Quiet programs and to explore proactive steps to ensure successful implementation. The aim was to stimulate the wider adoption of current and future engineering noise controls on machinery and equipment and to motivate the development and implementation of Buy-Quiet programs for the construction and manufacturing industries.

Beth Cooper at NASA has been the leader of a NASA program[24] to implement a Buy-Quiet program at all NASA facilities.

An international workshop on Buy-Quiet was held in Paris, France on July 5-6, 2011. William W. Lang and Jean Tourret presented a lead paper titled "Quieting the world by fostering a "Buy-Quiet" attitude among product purchasers." The paper and the abstracts from the workshop have been published in *Noise/News International*[25]

There are other drivers of Buy-Quiet programs.[26,27] Buy-Quiet programs offer several advantages[28]:

---

[19] Criteria for a recommended standard. Occupational noise exposure. Revised criteria 1998. Public Health Service, Centers for Disease Control and Prevention, National Institute for Occupational Safety and Health, Cincinnati, Ohio. 1998. DHHS (NIOSH) Publication No. 98-126.

[20] Royster JD, Royster LH [1990]. Hearing conservation programs: practical guidelines for success. Chelsea, MI: Lewis Publishers, pp. 73-75.

[21] Brogan PA, Anderson RR [1994]. Industrial noise control process. Paper presented at the Annual Meeting of the National Hearing Conservation Association, Atlanta, GA, February 17-19.

[22] Preventing occupational hearing loss—a practical guide. Cincinnati, OH: U.S. Department of Health and Human Services, Public Health Service, Centers for Disease Control and Prevention, National Institute for Occupational Safety and Health, 1996 DHHS (NIOSH) Publication No. 96-110.

[23] Haag W.M. Jr. [1988b]. Purchasing power. *Appl Ind Hyg* ***3***(9):F22-F23.

[24] Cooper, B.A, Development and implementation of policy-compliant site-specific buy-quiet programs at NASA. Paper in09-050, Proc. INTER-NOISE 2009.

[25] http://www.noisenewsinternational.net/archives/nni_193.pdf

[26] Bruce, R.D., Bommer, A.S., Lefkowitz, K.A., and Levesque, B.R., A new approach to noise control in the workplace. Paper in09-011, Proc. INTER-NOISE 2009.

[25] Nelson, D.A., A buy-quiet program incorporating career-cycle costs. Paper in09_154, Proc. INTER-NOISE 2009. 2009.

[28] Technology for a Quieter America. National Academies Press. Washington, D.C. 2010.

- In areas with hazardous noise levels, the noise hazard can be reduced, saving the costs of a hearing conservation program.
- Speech communication in low-noise workplaces is much better than in high-noise workplaces. In addition, because no hearing protection is necessary, desired sounds such as announcements via public address systems are not attenuated.
- Low-noise workplaces promote safety (e.g. alarms are clearly audible).
- Low-noise workplaces make it easier for workers to concentrate and reduce fatigue.
- Low-noise workplaces are more productive and more comfortable.

Beth Cooper at NASA's Lewis Research Center in Cleveland, Ohio, has published on Buy Quiet[29] and has developed a Buy-Quiet Roadmap and a template for a noise emission specification.[30,31]

The procedures for putting in place a Buy Quiet program include:

- Access to a database on machinery noise levels. Some are listed in the NASA Roadmap.
- Buyer and seller need to have knowledge of noise emission. Often, a primer is needed to bring buyer and seller up to speed on noise issues.
- Agreement on a metric, going with sound power level or sound pressure level, and selection of a noise emission standard.
- Agreement on specifications.
- Agreement on operating conditions.
- Whose noise is it? Sometimes the user is responsible.
- Emission vs. immission.
- Verification, which can be difficult to implement.

The National Institute of Standards and Technology (NIST) administers the National Voluntary Laboratory Accreditation Program (NVLAP), which is a program that testing laboratories can use to ensure that the laboratory is making noise emission measurements according to a specific national or international standard.

Verification is often difficult, in part because of reverberation and other machines on the factory floor. Bommer and Bruce[32] have outlined some of the difficulties with verification.

Product noise labeling is a part of Buy-Quiet program because the label carries the noise emission specification. The label could be a physical label or a statement in the product specification or other document. It is best to distinguish between consumer products and industrial products. The former should use a physical label because there is usually very little interaction between the buyer and the seller. For industrial products, negotiations are often possible so noise emission information can appear in other forms. Through a technical

---

[29] Cooper, B.A, Development and implementation of policy-compliant site-specific buy-quiet programs at NASA. Paper in09-050, Proc. INTER-NOISE 2009. 2009.

[30] http://buyquietroadmap.com/

[31] http://www.researchgate.net/publication/4697322_A_Buy_Quiet_Program_for_NASA_Lewis_Research_Center_Specifying_Low_Equipment_Noise_Emission_Levels

[32] Bommer, A.S. and Bruce, R.D. Making shop noise tests under difficult circumstances. Paper IN09_771, Proc. INTER-NOISE 09. 2009.

committee, INCE/USA is now studying the labeling issue with Matt Nobile leading the effort. His proposal is discussed in this report—in the above paper by W.J. Murphy.

There is more work to be done to encourage Buy-Quiet programs. International INCE has a technical study group (TSG-10) to make Buy-Quiet programs known to purchasers of equipment to which workers are exposed and to professional buyers; a draft document is currently being reviewed.

4
Engineering for Noise Control in Manufacturing

4.1 Progress and failures in U.S. manufacturing noise reduction

Robert D. Bruce, Principal, CSTI Acoustics

Bob Bruce described noise-control efforts within manufacturing, noting that the manufacturing industry has put less effort into noise control than other industries, such as aircraft and mining. A list of typical noise-producing machines used in manufacturing is in Table 4.1-1. “In 1948, after Slawinski,[1] a drop forge worker, developed hearing loss, filed suit against his employer in New York State, and won an award despite the fact that he had not lost any work time or pay.” Additional suits followed in New York and Wisconsin.

Table 4.1-1. Noise-producing machines common in manufacturing.

One successful example of improvements in production in a beverage can manufacturing plant was documented by Michael Bobeczko at Sukut Construction.[2] To make the cans, a roll of metal travels through a machine called a body maker that progressively punches the metal until it’s the right size for a can, then drops onto a conveyer. The A-weighted sound level ranged between 102-110 dB without controls. Through many clever design changes, they managed to reduce the A-weighted sound level by between 22-33 dB (all at 1 meter). The changes also improved production by 200 to 400 percent. See the table (4-5) on the following page which was extracted from the Technology for a Quieter America Report.

---

[1] Slawinski v J.H. Williams & Co., 298 N.Y. 546 81 N.E.2d 93 (1948)

[2] Technology for a Quieter America, 2010. Pg. 39.

The noise from punch presses depends on several things: the clearance around the punch, the thickness of the metal being punched, the shape of the punch, whether it's flat or at an angle, and the speed of the punch. Koss, in 1981, managed to reduce punch press noise by several means, for example, by adjusting the angle of the shear, (see Table 4.1-2).

TABLE 4-5 Noise Reduction and Productivity in a Beverage Can Manufacturing Plant

Manufacturing Equipment	A-Weighted Sound Pressure Level at 1 meter (dB)			Operating Speed in Cans/ Minute	
	Before	After	Noise Reduction	Before	After
Conveyors	110	77	33	600	2,400
Body maker	104	82	22	120	240
Trimmer	102	80	22	120	250
Necker/flanger	105	85	20	600	1,100
Scrap conveyor	105	80	25	600	2,400

SOURCE: Bobeczko, 1978.

Table 4.1-2. Punch press controls that reduce noise

TREATMENT	NR, dBA
Slant the face of the die—Modify the time history of the striking force	5 – 10
Use damping to reduce the radiation of noise from the equipment housing	2 – 5
Vibration isolate the press from the floor and other radiating surfaces	2 – 5
Secure the part being punched	0-10
Enclose the press	8 – 10

However, punch presses are still noisy for several reasons: The noise-generating mechanism is variable and is controlled by the user's dies and production materials; materials are not standardized; any data from punch press manufacturers might not be relevant if the same material and dies are not used in the factory. Why hasn't manufacturing become quiet? Because OSHA regulations are immission regulations on environmental noise in factories and not emission regulations on a specific piece of equipment.

The process industry is a different story. Valves are ubiquitous in process facilities, and they come with specifications that list sound levels. Sound level data are routinely available from manufacturers of motors, compressors, gears, coolers, etc. Valves are quieter today because in the 1960s the Navy had a valve problem. The steam admission valves on their submarines were very noisy and could be detected by enemy submarines, and they interfered with the ship's sonar. Dick Self and a colleague left NASA and designed the drag valve, opened their own business, Controlled Components, Inc., and went to Navy Labs, which provided testing capabilities. Additional incentives for producing quiet valves included OSHA requiements and community ordinances. Today, all three major valve companies sell quiet valves and routinely report the data to their customers.

All of the gas that heats homes travels through a series of compressor stations across the country to where it is used. Compressor stations can have major issues with environmental noise since the Federal Energy Regulatory Commission (FERC) limits their day-night average sound level limit of 55 dB(A) at the nearest inhabited residence. Dresser-Rand manufactures a 60 PSI single-speed compressor that would be ideal for compressor stations except it is very noisy, e.g. 110 dB(A) at 1 meter. As a result, the compressor station market would not buy them. An engineer at Dresser-Rand developed the Duct Resonator Array (DRA) which can be fitted at the exhaust nozzle of the compressor or in a pipe spool and provides 17 dB of noise reduction. It can work for broad band multiple tones as well, but provides less attenuation, typically 8 to 10 dB. These compressors and DRAs are now being sold routinely to the U.S. compressor station market and to international oil and gas firms.

Pneumatic tools, including air impact wrenches, air ratchets, jackhammers, pneumatic drills, and pneumatic nail guns, have standards controlled by trade associations (the Compressed Air and Gas Institute (CAGI) in the U.S. and PNEUROP, the European association of manufacturers of compressors, vacuum pumps, pneumatic tools and allied equipment) and the International Organization for Standardization (ISO). Early on, during noise testing, tools ran free with no impact; they did not have a load (work piece) associated with the tool. Now they are tested while operating on an isolated block.

In summary, other industries, including aircraft, power industry, process industry, mining, and electronics, have done a better job of adopting noise controls than manufacturing.

Steps that could help manufacturers reduce noise in their facilities include:

- Government sponsored programs to develop specific noise control methods.
- Better data about equipment noise from OEMs.

Economic incentives and better communications might turn the situation around. Bruce suggested convincing the manufacturing industry that:

- "Buying quiet" is the right thing to do.
- Quieter machines produce quieter environments, which will enhance production.
- Quieter machines can be just as powerful as noisy ones.

Also, convince the OEMs that:

- Manufacturing quiet machines is the right thing to do.
- Quiet machines will sell (it's good business).
- Quiet machines can be associated with phrases that imply a special quality that is desirable.

Finally, noise-control proponents should communicate

- The danger of hearing loss clearly and consistently.
- That sound levels at the ear with values greater than 75 dB could cause hearing loss.
- That if sound levels in industry were no greater than 85 dB, then everyone could be protected with earplugs.
- The appeal of "quiet."

4.2 Reducing employee exposures: A recent manufacturing plant example

Eric W. Wood, Director Emeritus, Noise Control Division, Acentech Incorporated.

Eric W. Wood, an acoustical consultant at Acentech, described a successful recent program to reduce employee noise exposures at a mid-size U.S. manufacturing facility. The goal of the noise abatement program, which is ongoing, is to define and install reasonable and effective noise controls that are acceptable to management, engineering, production, maintenance, and workers.

The target of the noise abatement program is to reduce noise levels to 80 dB(A) or less in frequently occupied areas.

Consulting steps provided by Acentech included:

- Meeting with plant managers, including engineering, operations, and safety
- Documenting current concerns and goals
- Measuring and defining plant areas and jobs with excessive noise
- Identifying principal noise sources and characteristics
- Preparing noise control plan of action
- Helping to implement selected noise abatements
- Determining if and where adjustments are needed
- Documenting results

For a noise abatement program to be successful, several additional recommendations , beyond the obvious need for excellent noise control engineering, are critical:

- Senior management must support the noise control program in keeping with their responsibility to provide a safe and healthful workplace
- Experienced plant and safety engineers should maintain ongoing ownership of the program
- Fully engage those responsible for production and maintenance
- Draw upon experienced noise control engineers for assistance

Wood addressed a range of noise sources at the plant and methods for reducing noise levels throughout large areas of the plant. For example, audible paging and alarm systems frequently produce loud noises throughout large areas of the plant. Acentech recommended installing a local-area network, providing vibrating alarm receivers for employees required to perform quick-response line repairs, providing cell-phone like receivers for employees being paged, and reserving the audible paging for emergency announcements.

Compressed air is used in many of the lines at this manufacturing plant to move, clean, and/or cool parts being made. To reduce noise from compressed-air vents, commercially available mufflers were installed on solenoids and low-noise jets are installed at many vents. In addition, compressed-air pressure and volume could be reduced at some locations to reduce both noise and operating costs.

Wood described the importance of understanding the frequency spectrum of individual noise sources when designing effective noise abatement methods. As an example, he described vibratory parts feeder bowls at the plant with noise-control enclosures that were lined with a thin sound absorptive material. However, the noise from the bowls peaked in the 125 Hz octave frequency band. To address noise at this frequency, the thickness of the interior sound absorbing should be increased to about 2 inches with an industrial-grade sound absorptive material providing greater low-frequency sound absorption.

One relatively small area of this manufacturing plant included air-handling ducts that radiated noise down to locations where employees are stationed full-time to remove completed parts from an assembly line. To reduce this noise, the ducts were lagged with sound absorbing insulation and aluminum sheeting.

To reduce the reverberant build-up of noise from the many items of plant equipment, sound absorbing panels were installed along the walls in selected plant areas.

Many of the operating lines included wire-mesh safety guards with hinges and line operating interconnects. These wire-mesh guards allowed workers to use long slender rods to move jammed parts off the line without opening the guards that would for safety reasons shut down the line. Acentech made two recommendations to reduce noise on these lines: install hinged transparent shields along the sides of the wire-mesh safety guards to reduce noise radiation. Install solid-metal covers with a lower layer of well-protected sound absorbing material above the lines to further reduce noise escaping from specific noisy lines.

This manufacturing plant included many roof/ceiling mounted propeller ventilation fans that contributed to the noise level throughout many areas of the plant. Installing commercially available tubular mufflers between the fans and lower workspaces could reduce noise from these fans.

Wood reported that the noise reduction program in selected noisy areas of the plant is ongoing as time and budgets permit. The plant owner, is pleased with the program and has reported that noise reductions of 2 dB(A) to 11 dB(A) have been achieved to date.

4.3 A history of noise control in the textiles, tobacco, and woodworking industries

Noral D. Stewart, President and Principal Consultant, Stewart Acoustical Consultants

Noral Stewart described the history of North Carolina's main industries, textiles, tobacco, and woodworking, and how noise control became important in the 1970s. He described the 1970s as "the Decade of Noise Control" driven by new OSHA regulations. The acoustics program at North Carolina State University (NC State) which had been started by NASA, shifted emphasis to workplace noise. Noise control efforts in woodworking started in 1970 and continued to 1978. Stewart became involved in a metal working program during his master's research in 1973 and that program continued to the late 1970s. Stewart shifted to a new textiles program in 1974, which continued until 1984. The tobacco industry had noise-control activities as well, with university assistance. In 1981, the NOISE-CON Conference was held, and John Johnson, then president of INCE-USA, stated that this program was the leader in the country on manufacturing noise control.[3]

C.D. (Dan) Mote, now president of the National Academy of Engineering, studied and designed noise reduction for saws at the University of California, Berkeley, and University of Maryland in the 1960s through the 1980s. Others followed, including Frank Hart and John Stewart at NC State, developing a helical planer, which has since moved into consumer markets, and optimizing design of carbide tip saw blades to reduce noise. John Stewart at NC State did a major demonstration of a noise control program in a large furniture factory, documenting the controls and their costs and published his work in various INCE proceedings.[4] Quieter planers and saws are in wide use in lumber mills, although much of the furniture industry has moved overseas.

The textile and textile machinery industries are essentially the oldest in the United States. These were not high-precision machines. Adjustments were made with a hammer. In a weave or spinning room, the noise level was typically at 95 dB(A) to 110 dB(A).

North Carolina's Textile Industry Program, sponsored by NIOSH in the 1970s, was started by NC State's Ron Bailey, Frank Hart, and Paul Emerson. Tom Hodgson joined later. The program worked on a wide variety of problems. The group held regular meetings with industry to share results. Major textile companies—Burlington, Hanes, Fieldcrest Cannon—and machinery companies—Whitin, Platt, and Saco Lowell—were heavily involved. Some large textile companies established their own strong programs. Burlington Industries had five or six people working full-time on noise control. The emphasis was on reducing noise of existing old machines, with an emphasis on spinning yarn and weaving cloth, which is where most employees were exposed to noise. Some projects focused on other areas, such as roving, twistng, and winding. Much of this work was published in INCE/USA proceedings.[5,6,7,8,9,10,11]

---

[3] Personal communication.

[4] The past ten years of noise control in the woodworking industry, Stewart, J.S., Inter-Noise 82, San Francisco CA, pp 245-248(4)

[5] An investigation of noise radiated by an eccentrically rotating bobbin, Evans, J.D.; Emerson, P.D.; Ronald, Bailey J., NoiseCon73, Washington DC, pp. 423-427(5)

For ring spinning, the machinery was in large rooms of perhaps 100 machines of 300 spindles each. The NC State researchers identified the noise source and developed retro-fit controls, finding certain spindles were quieter than others. They showed that room levels of 90 dB(A) could be achieved for spindle speeds up to 13,000 rpm, a 10-dB reduction in noise. A major source of noise was the loose spindles, which had to be kept loose for manual replacement. Today, that process is automated, so spindles are tighter and quieter.

Some work on modern looms was successful but the fly-shuttle loom which was widely used proved more challenging. Early work, as reported by Cudworth,[12] indicated that adjustments and resilient parts could reduce noise, but controls proved impractical. After many efforts, Hodgson concluded that progress was impossible. Fortunately, today's weaving machines are significantly quieter.

The tobacco industry started small, choosing a simple fix that was not expensive in order to convince management of feasibility. They began with a filter-making machine and managed to reduce noise by 9 dB for less than 1 percent of the machine's cost. Results were published in *Noise Control Engineering Journal* and management was convinced of its utility.

The two largest companies, Reynolds and Philip Morris, took the lead, aiming for improved productivity and noise reduction simultaneously. They concentrated on machine design improvements and room improvements, adding absorption into the ceiling, for example. They were doing their own machine research and development. Before a machine was put into production, they were making more than 100 productivity improvements and noise reduction changes to a new machine. So they went to the manufacturers and told them to make the necessary changes before sending the machines to North Carolina, "If you don't do it, we're going to start building our own machines." That got attention.

Today, these industries are no longer dominant in North Carolina. Fewer people are working in manufacturing overall. The remaining textile and tobacco operations, however, are much more productive and quieter. And a bit of a turnaround has begun. Companies from China and India are building textile plants in North and South Carolina. And smaller, boutique furniture-making shops are in business.

Some lessons learned: efforts to quiet older technology often have little lasting effect. Stewart encourages industry to look to the future and don't spend efforts retrofitting an old machine if it will be replaced in four or five years. For lasting impact, work with manufacturers to develop a quieter new machine at the point of production.

---

[6] Noise associated with rings on textile ring spinning frames, Stewart, Noral, D. and Bailey, J. Ronald, NoiseCon81, Raleigh NC, pp. 183-186(4)

[7] Transient noise source identification in a fly-shuttle loom, Caliskan, M.; Cooke, J.A.; Bailey, J.R. , NoiseCon81, Raleigh NC, pp. 31-36(6)

[8] Fly-shuttle loom picking mechanism vibration studies using finite element analysis, Caliskan, M.; Bailey, J.R.; Hodgson, T.H., NoiseCon81, Raleigh NC, pp. 187-190(4)

[9] Finite element analysis applied to open-end spinning noise, Cooke, J.A.; Bailey, J.R., NoiseCon81, Raleigh NC, pp. 195-198(4)

[10] Noise investigation of the picking mechanism in an air-jet loom, Fogleman, E.W.; Hodgson, T.H., NoiseCon81, Raleigh NC, pp. 191-194(4)

[11] Noise investigation of a yarn twister-winder, Handschy, M.S.; Hodgson, T.H., NoiseCon81, Raleigh NC, pp. 199-202(4)

[12] Cutting out noise from the whole cloth: Noise control in the textile industry, Noise Control Engineering Journal, **1**, 24-31, 1973

4.4 Noise Reduction and productivity improvement for a paper shredding operation

Noral D. Stewart, President and Principal Consultant, Stewart Acoustical Consultants

Noral Stewart offered a case study of a project that enabled noise reduction along with improved productivity. This work occurred at a company that used paper disintegrators to convert postcard-size pieces of paper into confetti. The problems involved noise exposure as well as inefficiencies. The noise sources were the paper disintegrators as well as the associated vacuum cleaners that helped pull the confetti out of the machine. The company had purchased an enclosure for one of the machines, but because the machines were clogging, the enclosure was not in use. Employees had to constantly take apart the machine to clean out the clogs, which slowed their processes. Workers were receiving overtime pay to keep up with demands.

The chopper used in the paper shredder is similar to choppers used in many kinds of industrial situations. With two adjacent machines, operators stood at the shredder and fed the paper from a table into the hopper at the top, where noise reverberated. The attached vacuum cleaners were also very close to the employees' ears (Figure 4.4-1).

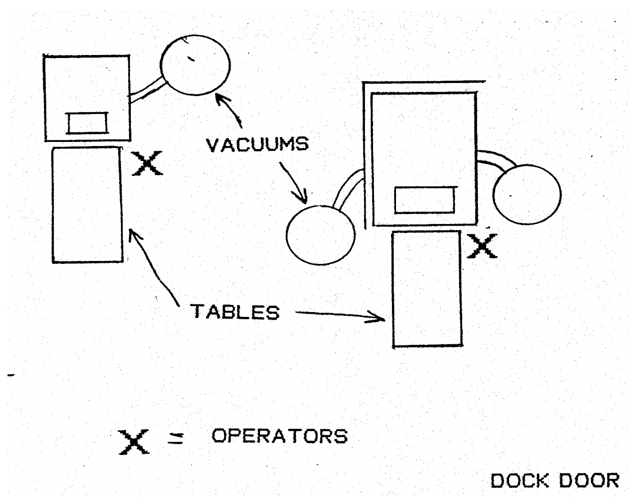


Figure 4.4-1. Set up of two paper disintegrator stations.

During the evaluation, workers were exposed to noise levels in about the mid-90s. The project had several goals: 1) reduce the time weighted average exposure of workers to 88 dB or less, 2) increase productivity of the machine, 3) minimize impact on the nearby loading dock, and 4) minimize non-recoverable costs. The company was willing to buy a piece of equipment if they could sell it later they chose to discontinue operations.

Stewart and colleagues aimed to eliminate the clogs, reinstall the enclosure and increase productivity. Because the vacuums were a major noise source, they looked at ways to reduce or eliminate them. And they looked for a way to move the operators away from the noisy machine, reduce the machine's noise, or both.

They took several steps to meet the goals:

- Damped machine surfaces to reduce source noise by approximately 5 dB
- Replaced vacuums with small cyclones that were quieter and had fewer clogs
- Installed conveyors to carry the paper into the disintegrators, further reducing clogs and allowing workers to stand away from the noise source

- Installed enclosures and floor isolation systems on both disintegrators.

With the new set up, Figure 4.4-2, the noise was reduced more than expected, down to about 84 to 86 dB. Productivity improved and overtime was eliminated.

Figure 4.4-2. *Solution enabled operators to stand further from noisy disintegrator.*

4.5 Evaluation of noise exposure at a metal conduit manufacturer

Scott E. Brueck, Senior Industrial Hygienist, National Institute for Occupational Safety and Health

Scott Brueck described a program of the National Institute for Occupational Safety and Health (NIOSH) called the Health Hazard Evaluation (HHE) program and provided an example of an evaluation at a metal conduit manufacturer that focused on employee noise exposures.

NIOSH and the Occupational Safety and Health Administration (OSHA) were created as part of the Occupational and Health Act of 1970. OSHA, part of the Department of Labor, is responsible for issuing and enforcing workplace safety and health regulations. NIOSH, at the Department of Health and Human Services, does research, surveillance, education, and worksite evaluations.

The purpose of the HHE program, which also was mandated as part of the OSHA Act of 1970, is to evaluate possible health hazards at a workplace and make recommendations to eliminate hazards and prevent work-related illness when health hazards are found. NIOSH does not issue citations or perform enforcement actions. HHE's are performed by request only. Requests for a HHE can be submitted to NIOSH by employees, employee representatives, employers, or another government agency. There is no cost to the requestors and the findings and recommendations of the HHE are submitted to the requestors[13] in a report that is also publically available on the NIOSH HHE program website.

Brueck described an employee-requested noise-related HHE at a 400,000 square foot plant with 168 production employees manufacturing galvanized steel conduit with diameters ranging from 0.2 to 4.0 inches. Evaluators identified four principal sources of noise (illustrated in Figure 4.5-1):

- metal conduit rolling or dropping on to other conduit
- metal conduit striking metal parts of production equipment
- operation of production equipment
- a steam cannon used to clear fluid from inside conduit

During HHEs, NIOSH investigators often observe poor maintenance of equipment, which leads to rattling, squeaking, and leaking of compressed air. These are all examples of workplace noises that can be easily reduced or eliminated with proper equipment maintenance.

At this manufacturer, brief peak noise levels ranging from 100 to 135 dB were measured in production areas. NIOSH measured representative full-shift time weighted average (TWA) noise exposures for many production workers. The TWA results ranged from 86 to 103 dB(A) when measured with a dosimeter set to the NIOSH recommended 3-dB exchange rate. With the 5-dB exchange rate used by OSHA, the results ranged from 72 to 95 dB(A). Brueck pointed out that Type 2 dosimeters could under report TWA noise exposures from high-level impulsive noises such as experienced in some production areas at this conduit plant. Mr. Brueck noted that some employees had hearing threshold shifts. He recommended that the company review and track workers' hearing loss at all audiometric test frequencies and use both NIOSH and OSHA criteria to identify hearing threshold shifts.

[13] Company names are no longer included on HHE , but at the time this report was completed the HHE program still included the company name on the report.

***Figure 4.5-1**. Principal Sources of Noise at the Conduit Manufacturing Plant.*

Brueck complimented the management at this manufacturing company for requiring all production workers to wear hearing protectors and for making several types available. However, NIOSH investigators observed that some emplyees did not properly insert foam ear plugs. He noted that hearing protectors alone did not provide enough protection for employees working near the steam cannon due to high impulse noise and TWA noise exposures greater than 100 dB(A). Hearing protector fit-testing and training can help companies effectively provide employees with guidance on achieving proper fit of hearing protectors.

The HHE report for this conduit manufacturing plant included recommendations directed at both installation of specific engineering noise controls and also administrative controls. The engineering control recommendations included:

- Reduce distance that conduit rolls or drops before striking other conduit
- Decrease speed at which conduit rolls before striking other conduit
- Replace metal pickups on conveyor chains with nylon pickups
- Increase thickness of metal stop plates to increase damping
- Construct partial enclosure or barrier at steam cannon

The administrative control recommendations included:

- Require employees working near the steam cannon to wear ear plugs and muffs
- Advise contractors on hearing protection requirements

- Retrain employees on how to properly insert foam hearing protectors
- Give supervisors responsibility and accountability for ensuring proper use of hearing protection
- Review and track hearing loss at all audiometric test frequencies and use both NIOSH and OSHA criteria to identify hearing threshold shifts

After submitting the HHE report, NIOSH sometimes requests the opportunity for a follow-back site visit to learn what information in the report was useful and which recommendations have been implemented. At a follow-back visit to this conduit manufacturing plant two years after the HHE report was completed, NIOSH investigators found that the company had built an operator enclosure near the steam cannon, a second operator enclosure was in the planning stage, and nylon stop plates had been installed to reduce the noise of metal-to-metal contacts.

A copy of the HHE report for this conduit manufacturing plant is available.[14]

[14] Rodriguez M, West, CA, Brueck SE. Evaluation of Worker Exposures to Noise, Metalworking Fluids, Welding Fumes, and Acids During Metal Conduit Manufacturing. Health Hazard Evaluation Report. HETA 2006-0332-3058. April 2008. http://www.cdc.gov/niosh/hhe/reports/pdfs/2006-0332-3058.pdf

4.6 Benefits of noise reduction in a manufacturing environment

Michael Roberto, Environmental Safety and health Supervisor, General Dynamics-OTS

Michael Roberto, an experienced environmental health and safety professional, described the successful noise-reduction efforts at General Dynamics' Ordinance and Tactical Systems plant in South Central Pennsylvania. The plant is a metal parts manufacturing operation that has been serving commercial and military markets for 50 years.

The plant's noise abatement treatments have improved the working environment and productivity, reduced operating costs, and improved product quality. The plant consists of 300,000 square feet of buildings located near a residential area. Pipe joints and swivel joints are produced for the natural gas and oil drilling industries. Metal parts are forged, machined, welded, painted, and coated for defense industry customers.

Manufacturing and inspection processes at the plant include:

Tool & Machine Shop	Rubber & Plastics Molding
Developmental & Low Rate Production	Hard Coating, Zinc Plating, Anodizing
Gage Manufacture & Calibration	Product Assembly
Hydraulic & Mechanical Forging	Ejector Deep-Hole Drilling
Continuous Heat Treatment	Mechanical and Non-Destructive Testing
Phosphatizing and Painting	Welding
2 & 4 Axis CNC Machining and Milling	Abrasive finishing

The company's president consistently expresses a commitment to safety as a high priority at the plant. For noise, the company aims to protect its employees[15] as well as the surrounding residential community. Noise reduction is important because it protects employees and can improve the bottom line by reducing energy consumption at the plant. Management has learned that less noise on the factory floor also leads to improved product quality.

The plant embraced hearing conservation via personal protective equipment during the early 1990s and matured into noise reduction through engineering controls. It has recognized the benefits of investing in equipment that produces less noise. Several examples follow:

Old roof fans were replaced with new high-efficiency fans, which lowered the noise below the fans and also reduced energy usage. Noise from a vibratory bowl feeder was loud for workers who were operating a machine 10 feet away. Enclosing the bowl feeder (Figure 4.6-1) reduced the noise by 30 dB, from 116 dB(A) to 86 dB(A), and enabled the machine operators to hear if their machine was functioning properly. Efficiency and product quality have improved.

[15] See Meinke D.K. and Morata T.C., Awarding and promoting excellence in hearing loss prevention. Int J Audiol. 2012 Feb. Suppl 1:S63-70. PMID: 22264064

Figure 4.6-1. *Enclosure for a Vibratory Bowl Feeder.*

The company purchased a new injector drill (Figure 4.6-2) with a sound enclosure for a deep drilling operation. The enclosure has reduced the noise by 15 dB, from 110 dB(A) to 95 dB(A). Employees working in the area still must wear hearing protection, but the noise reduction is significant.

Figure4.6-2. *Enclosure for an injector drill.*

New high-pressure coolant pumps have been installed at various metal cutting operations. These new pumps produce more pressure and more volume directly at the cutting tools. This has reduced chip buildup at the tools, lengthened tool life, and reduced the high-pitched squeal from 110 dB(A) to 87 dB(A). This represents another significant noise reduction together with improved manufacturing operations.

Through focused efforts at “lean” projects, the company was able to reduce the number of machines required to produce certain products. The result is greater efficiency and less noise.

This manufacturing plant, like many others, used a lot of compressed air produced by old and inefficient compressors located in a separate compressor room where the noise levels exceeded 100 dB(A). Several steps are under way to reduce the use of compressed air to lower compressor-operating costs and reduce noise levels. Old inefficient compressors are being retired and replaced with modern efficient quieter compressors. During regularly scheduled air-leak surveys, the maintenance group is replacing traditional hose clamps with a new crimping device that improves the quality of the connection and is decreasing the number of air leaks. Also, old nozzles used to clear shavings are being replaced with the commercially available efficient nozzles that get the job done with less air flow and less noise. These steps have reduced plant operating costs and reduced employee noise exposures.

The workforce at this plant is comprised of dedicated hard-working people, the large majority of whom have 35 or more years of experience. As one measure of the success of engineering noise controls at this plant, there has been only one OSHA recordable hearing loss case from 2005 to 2013, a significant improvement over prior years.

Following Roberto’s presentation, there were questions and discussions about non-occupational noise exposures some employees receive during recreational activities, such as hunting or farming. A recommendation provided was that hearing conservation managers should a) allow employees to bring hearing protectors home and b) strongly encourage employees to follow good hearing conservation behaviors both at work and outside the workplace.

5

Innovative Techniques for Engineering Noise Control

5.1 Advanced methods for noise source localization on machines

Earl G. Williams, Senior Scientist, Acoustics Division, Naval Research Laboratory, Washington DC

Earl Williams has been with the Naval Research Laboratory for 32 years carrying out innovative basic research in acoustics. In this presentation, Williams explores advanced techniques for visualizing sound fields and for obtaining quantitative information on the properties of those fields. This contribution outlines advanced techniques for the measurement, evaluation, and understanding of noise sources, and how these techniques can be used both to quiet noise sources and reduce the noise exposure of employees in manufacturing environments.

Over the last 30 or so years, there have been major improvements in microphone arrays. The use of microphone arrays makes it possible to do more and develop better information about sources of sound. It is not only the array, but the electronics and software that come packaged with the array that bring these devices to the forefront of source identification techniques.

One company, GFaI in Germany, uses a beamforming technique in an "acoustic array camera." Other companies active in this field include LMS, Norsonic, and Brüel and Kjær. A few commercially available microphone arrays are shown in Figure 5.1-1.

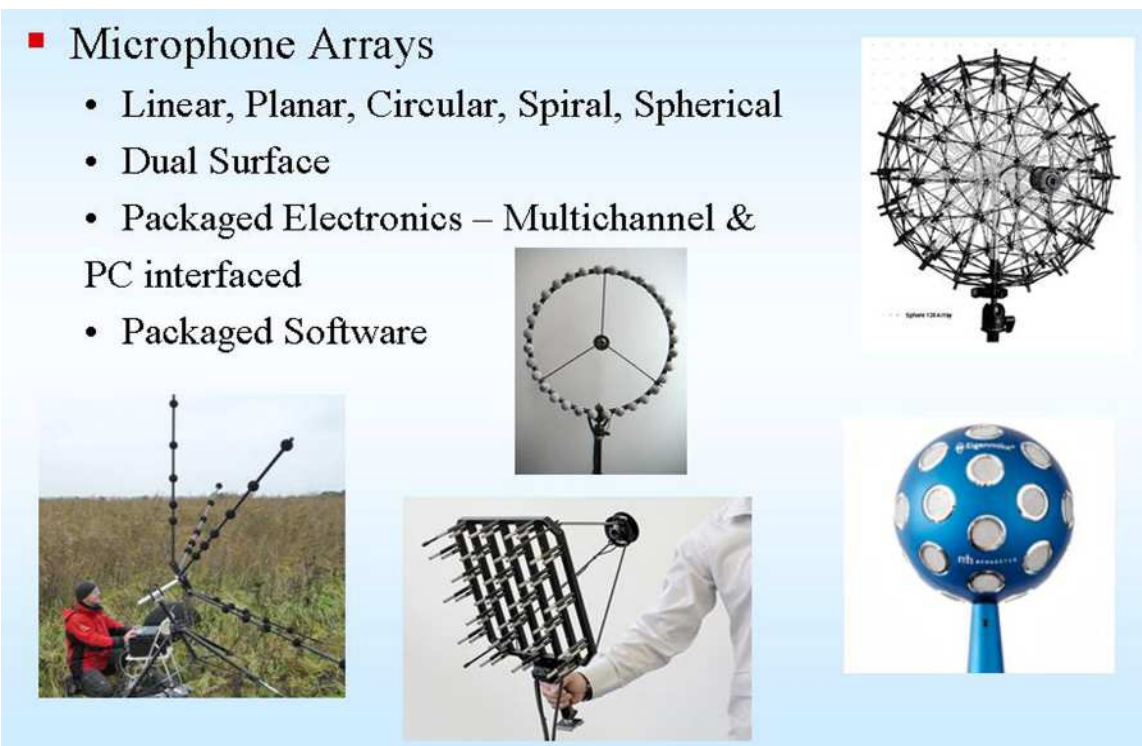


***Figure 5.1-1.**. Various commercially available microphone arrays.*

Beamforming is not a new technology, but, coupled with electronics and software, it can create 2-D images of where sound is coming from for a particular source. Basically, a qualitative image is created. The term qualitative is used because the image does not represent a physical quantity such as sound pressure level, sound power level or spatial intensity. One example is the imaging of a shredder in a room[1] using a 120-microphone array and beamforming methods. The microphone array and the image are shown in Figure 5.1-2. Note the faint reflections from the ceiling.

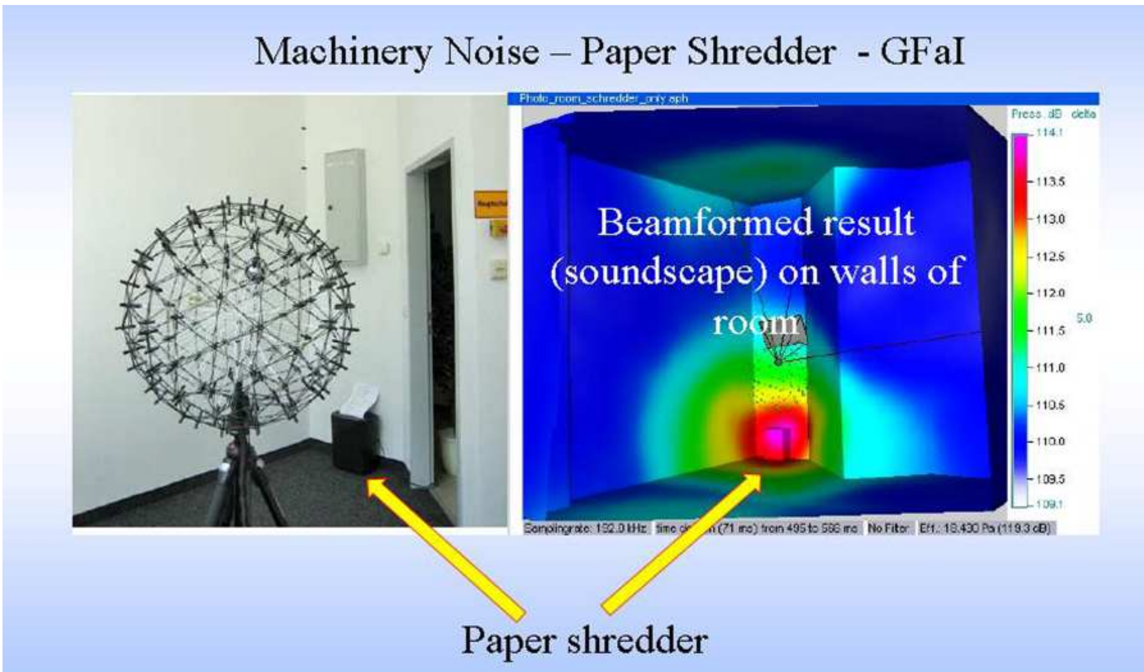


Figure 5.1-2. *Soundscape from a paper shredder.*

Another application involves a visualization of the sound field radiated from a wind turbine. Figure 5.1-3 illustrates that much of the noise in this example comes from tip vortices at the ends of the turbine blades.

Noise source localization can also be accomplished using spherical microphone arrays that reconstruct and identify a spatial distribution of incident plane waves. The theory behind this technique uses spherical harmonics, a powerful mathematical construction used extensively in physics and engineering. Just as a time function can be expressed as a Fourier series in the frequency domain, a sound pressure distribution on the surface of a sphere can be expressed in terms of a series of spherical harmonics. The next step is to extract from the spherical harmonics a series of plane waves coming toward the spherical microphone array from all directions whose amplitudes and phases just match the sound pressure distribution on the sphere. As before, this technique provides information on the plane waves, and thus can be used for source localization. The angular resolution of the array is very important. An array of 400 microphones has an angular resolution of about 20 degrees. The array can be thought of as sort of a zoom telescope; the more microphones, the more you can zoom in on specific sources. The resolution of an array in terms of the number of microphones used is shown in Figure 5.1-4.

[1] From GFaI literature.

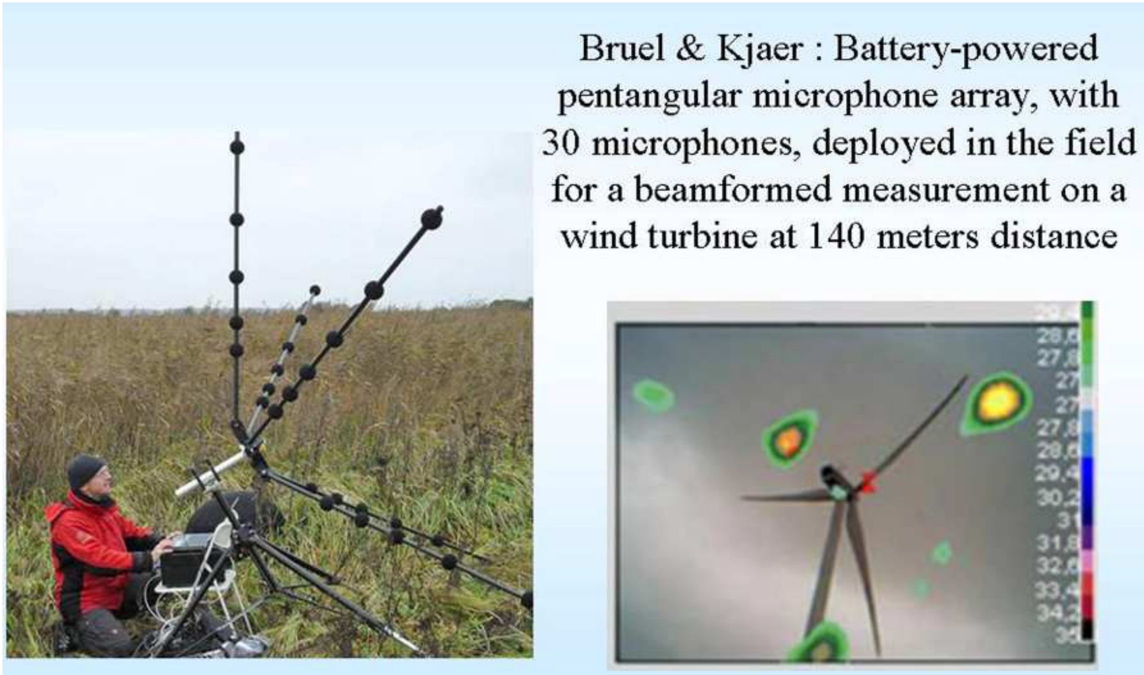


Figure 5.1-3. *Imaging of the sound field from a wind turbine.*

Imagine these techniques used in a manufacturing environment, say at a workstation, where sounds come from different directions. This technique allows the room, the ceiling, the floor, and the walls to be scanned to determine the locations of sound sources.

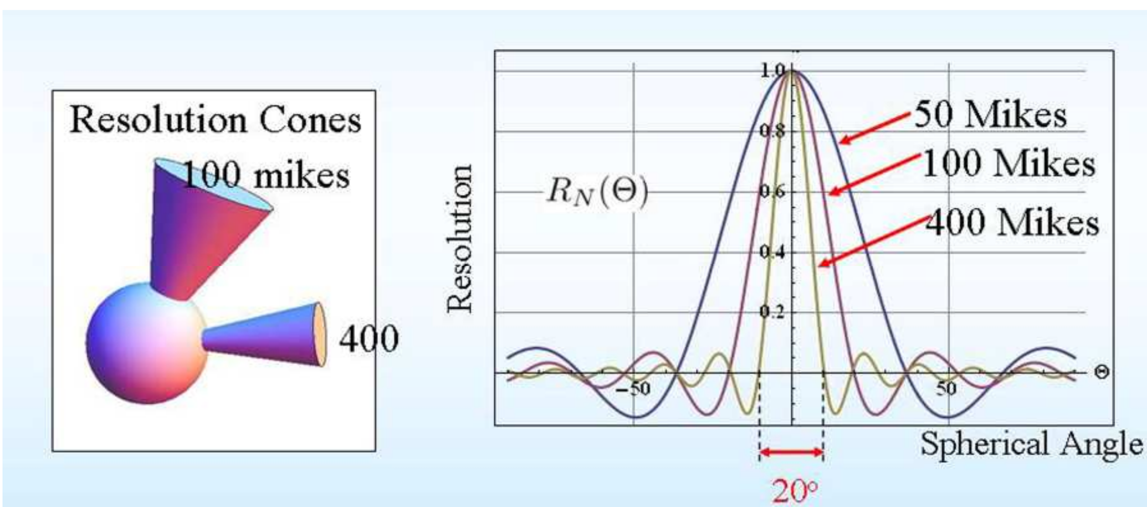


Figure 5.1-4. *Spatial resolution of a microphone array.*

Another set of methods capable of providing quantitative information on the properties of a sound field is known as inverse methods, which are based on the physics of sound propagation, in particular near-field acoustical holography (NAH). Here, an array of microphones is placed in the near-field of a sound source. The image seen by the array can be propagated back to the source using software to determine the hot spots of the source that contribute to the radiation.

NAH has been available for many years. For example, the Naval Research Laboratory has a 1980s patent on the basic technique.

Think of a noise source placed in an anechoic, or echo-free, room and radiating sound in all directions toward the anechoic surfaces of the room. The sound field near the source (the near-field) is much more complex spatially than the far-field, which consists mainly of simpler spatial patterns. In the near field, the sound pressure can be measured using an array of microphones and mathematics can be used to propagate the pressure field back to the surface of the source, essentially traveling backwards in time. That is why it is called an inverse method. Using this method, the sound pressure and sound intensity (power per unit area) at the surface of the source can be determined, yielding a significant aid to source identification. One important result from using NAH is that quantitative information can be obtained about the sound field. Sound pressure, particle velocity, and sound intensity can all be calculated as well as the total power radiated to the far-field.

An example of near field holography comes from research done by the author at the Pennsylvania State University. The sound source was a shaker-driven simple plate with a rib. See Figure 5.1-5.

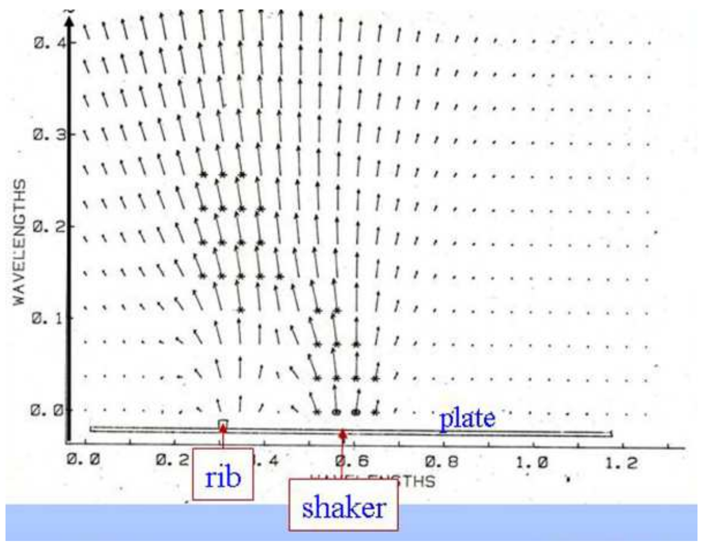


Figure 5.1-5. *Flow of sound intensity above a shaker-driven plate derived from NAH. The sound sources (the rib and the shaker) can be identified by the intensity vectors.*

One interesting result of propagating the field back to the source (lowest row of vectors in the figure) is that the sound radiation from the rib is uncovered. The rib source is not evident, however, on the top row at 0.4 wavelengths from the plate surface. Years later when working at NRL, it became clear to the author that when ribs are placed on the hull of a submarine, the radiation of sound from the hull is enhanced. Of course, submarines need ribs so they don’t collapse. But there is a fundamental message in this experiment: given a surface with a very complicated vibration pattern, constraining the motion by some sort of a rib can cause a substantial increase in the sound radiated from the surface.

Although not shown in the above image, at points on the plate away from the shaker and rib, intensity vectors go both into and out of the plate creating what is called an acoustic short circuit. This always occurs when the structural wavelengths are smaller than the acoustic wavelength of the radiated or scattered field. This variation in intensity has been a problem for engineers who use intensity probes to scan vibrating surfaces to determine the source of radiation because nearby vectors that go both in and out of the plate tend to cancel each other. This makes it difficult to identify sources. One example would be the side of a sheet-metal enclosure where the vibration patterns are complex and most of the sound radiation comes from near the (constrained) edges of the enclosure.

Another application of NAH was developed at the Naval Research Laboratory. In this case, a shaker attached to a sidewall inside a cabinet was used as a sound source, and a scanning microphone was used to determine the induced sound field over a two-dimensional surface, called a planar hologram. Figure 5.1-6 shows the reconstructed bipolar vibration patterns at three frequencies of the back of the enclosure. At the bottom of the figure, the total far-field sound power determined from NAH as a function of frequency is shown. Three peak frequencies in the sound power spectrum are indicated by arrows that correspond to the vibration patterns shown.

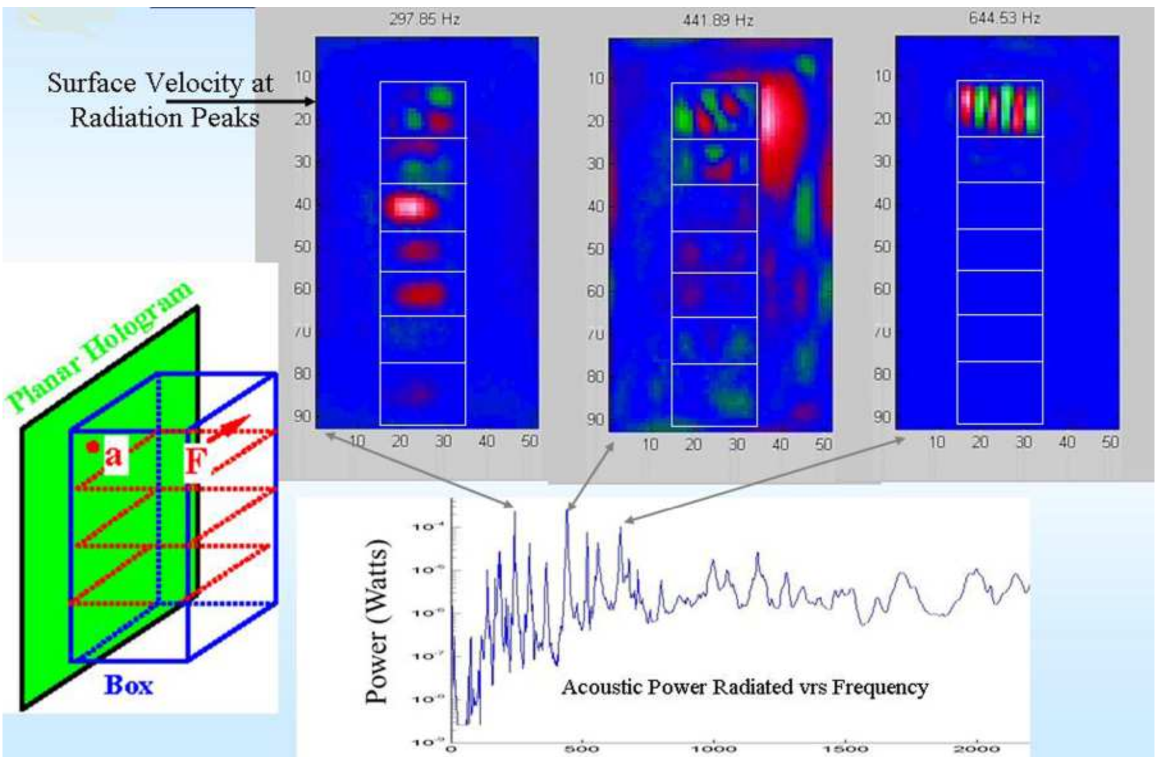


Figure 5.1-6. An inverse method (NAH) yields surface velocity on the back side of the cabinet.

In summary, advanced technologies of measurement include various microphone array configurations from line to spherical arrays. Beyond measurement, there are technologies for evaluation and understanding. These include:

- **Beamforming** - Source localization via color 2D maps, higher frequency, wavelength resolution, acoustic power not provided,
- **Wave Expansion** - Physics based 2D maps, surface reflectivities, and
- **Inverse Methods** - NAH based 3D maps of pressure, velocity, intensity vector, sound power ranking of machine sources; low frequency, high resolution.

These technologies can be useful in the localization, identification, and reduction of noise from equipment made for use in manufacturing environments.

5.2 Advanced computational techniques for noise reduction: modeling and simulation of compressors and pneumatic tools

Michael Lucas, Principal Engineer, Ingersoll Rand, Davidson, North Carolina

Michael Lucas has been working for Ingersoll-Rand for more than 15 years. His primary responsibility is the evaluation and control of noise generated by compressors and pneumatic tools. Prior to joining Ingersoll-Rand, Mr. Lucas worked at Wyle Laboratories Acoustic Research Division for 13 years.

Introduction

Many advanced engineering teams leverage the cost benefits of modeling and simulation to decrease the time it takes to develop a new product and to improve product reliability and performance. A typical new product development project can cost upwards of 10 million dollars or more. There are tremendous cost benefits to use modeling and simulation and, for this reason, most major corporations now rely on computer modeling and simulation when designing a new product.

The primary source of noise generation in air compressors and pneumatic tools is the pressure pulsations that are generated from the high speed of gas flows within the flow paths of turbomachinery components. Interactions of the flow with rotating mechanical components frequently produce large pressure pulsations that become the major source of noise (greater than 10 psi peak-to-peak). The most cost effective approach to reducing the noise generation is treating the noise at the fluid pressures dynamic source. To overcome these problems in the design process, noise control engineers simulate the flows to gain an understanding on the noise creating mechanism and study how these interactions can be modified to reduce the pressure pulsations.

Computational Fluid Dynamics (CFD) provides the means for understanding these unsteady flows. However, the modeling of these flow regimes is complicated by the rotation of moving parts. To overcome these problems, a concept called “moving mesh” is applied that describes the time dependent flow domains. The flow domain by definition is the space occupied by the fluid at a given instance. In turbomachinery applications the flow domain is time dependent on the rotational speed of the parts.

Besides using CFD for noise prediction, one of the many benefits to using CFD is to identify improvements in power and efficiency. Compressed air systems alone account for 10% of all the electricity use and roughly16% of all motor system energy use for U.S. manufacturing industries. More than 70% of all manufacturing facilities in the United States have some form of compressed air system. Compressed air systems are used throughout the manufacturing operations including material handling, pneumatic tools, pumping systems, and instrument air for process controls.

The interaction of the aerodynamic field and the acoustic field largely depends on the acoustic feedback mechanism. External flows are typically parabolic in nature; the action of the fluid dynamic flow is independent of the acoustic field. For example, a propeller fan flow has little interaction with the far-field acoustic field created by the air motion. An internal flow is elliptical in nature; the interaction of the acoustic field with the fluid dynamic flow is intertwined. For example, an organ pipe resonator maintains a single frequency of the organ pipe resonator despite the amount of air that is blown through the orifice.

The selection of the CFD solver for internal flows in turbomachinery requires high order accuracy to predict both the fluid dynamic and acoustic pressure fields. The problem lies in the orders of magnitude between the aero-dynamic and acoustic pressure fields. A fluid dynamic pressure field typically has unsteady pressures greater than 10^5 Pa while an acoustic pressure field can have pressure fields of several Pascal's or less.

Moving Mesh

Moving geometries require a mesh generation for each time step. In turbomachinery applications, a time step is described as a degree or fraction of a degree in rotation. Each rotational mesh must be created from the same mesh topography for each time step so that the CFD solver can resolve the individual motion of the elements. The CFD solver then solves for the flow between the elements as each mesh is read into the solver.

When working with these types of problems it is critical that the time steps and the mesh movement are sufficiently small to avoid the introduction of numerical errors. Whenever there are tight clearances between the parts, the level of difficulty of solving these problems is compounded because the mesh elements are highly compact within a very small region of the flow domain. One problem that is particularly difficult to solve is the flow inside a screw compressor. Besides the tight clearances between the interlocking rotors, the counter rotating helix shape of the male and female rotors can easily cause the mesh elements to fold onto themselves. A folded mesh is a term used to describe a negative volume of a mesh element. A single folded mesh contained within millions of mesh elements will cause the CFD solver to fail.

Described below are the differences of structure meshes and overset meshes with application to turbomachinery. Figure 5.2.1 shows an overset mesh for a propeller fan. This as an overset mesh because the flow domain is composed of many individual meshes that lie on top of each other. In this figure is shown the surface meshes that outline the shape of the propeller. Not shown in this figure is the volume mesh that expands outwardly into the flow domain. It is the superposition of all volume meshs that is used by the CFD solver to model the flow domain.

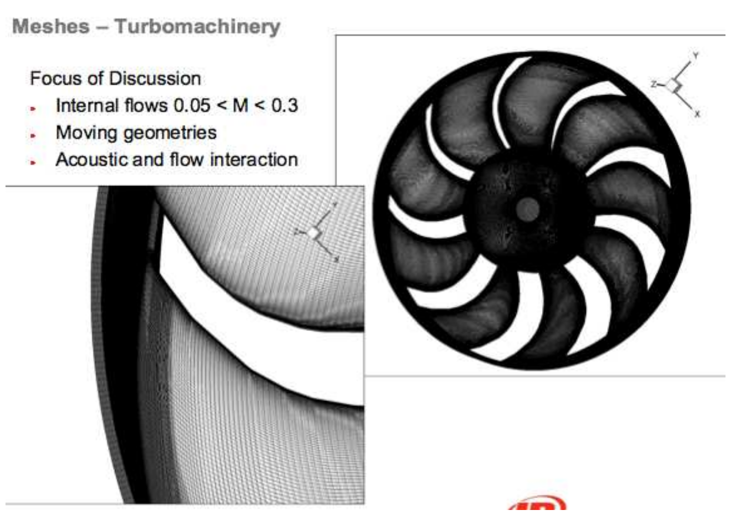


Figure 5.2-1. *Overset surface mesh for a propeller blade.*

The example described below is for a roots blower. The product shown in Figure 5.2-2 is a low pressure blower that has an operating range between 0 and 1 bar gage pressure. The inlet flow at 1 bar is approximately 1100 icfm,[2] and the required power to drive the compression cycle is 90 hp. Contained within the rotor housing are two identical rotors. Figure 5.2-3 shows a top level assembly drawing. The CFD model used in this analysis contains only the air passages formed between the rotors and the housing. Not included in the model are the bearing assemblies and rotor seals. Only the housing and the rotors are used in the CFD modeling.

Figure 5.2-4 presents an example of the blower mesh at one time step. The analysis used a structured quad mesh that has approximately 5 million elements. In this example the rotor turns within the housing and for each time step there is a new rotor mesh. Each rotor mesh has the same number of identical elements and connectivity, only the mesh position is allowed to change between time steps. A close-up view is shown in Figure 5.2-4b where the clearance between the rotors is approximately 50 microns (0.05 mm). Packed between these two sets of rotors are approximately 15 rows of mesh elements that are spaced approximately 3 microns apart.

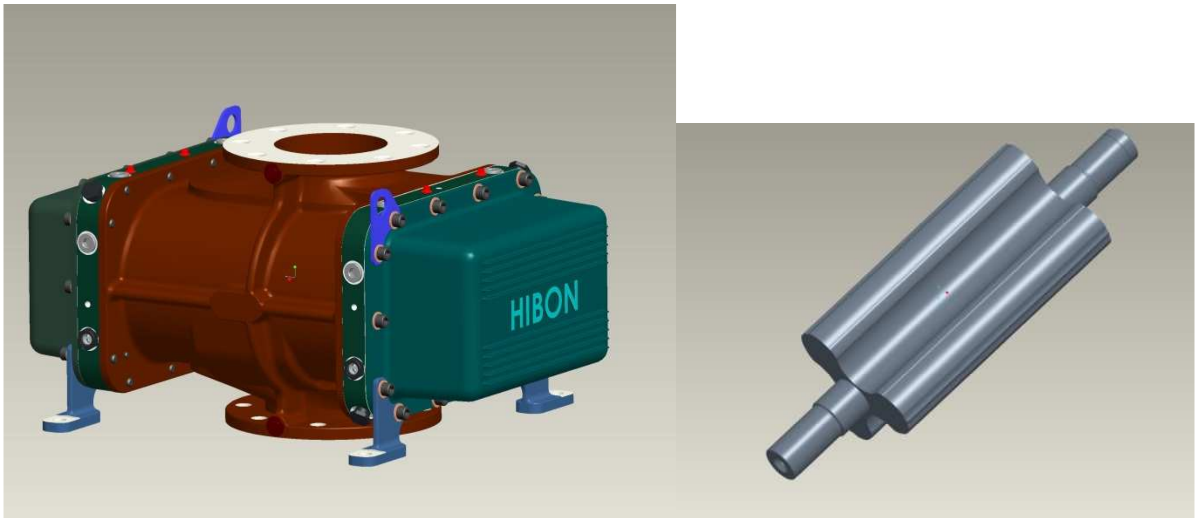
Figure 5.2-5a illustrates an overset mesh for the same geometry. There are approximately 40 individual meshes that make-up this entire model. The element count is approximately 80 million elements and between the two sets of rotors the element spacing is nearly 0.5 microns. Figure 5.2-5b shows an example of how these meshes overlay with one another. The beauty of the overset techniques is the fidelity of the meshes that can be achieved within the closest of spaces. The overset mesh technique does include the boundary layer while the system of meshes shown in Figure 5.2-4 does not include a boundary layer.

Modeling the clearances is critical in turbomachinery CFD calculations. The areas of greatest interest are the gaps between the rotors, and the gaps between the rotor tips and the housing. Most of the important flow action occurs between these gaps, and capturing these effects is very important for accurate flow predictions. It is not uncommon to have supersonic flows between the clearance gaps. The pressure gradients that come with these flows often are the most important factor when calculating the machines efficiencies.

The accuracy of these predictions is shown in Figures 5.2-6 and 5.2-7. In the figures the blue line represents the predictions made using a system of individual meshes. The red line presents the results for the overset mesh. Overall the predictions are very good considering the complexity of the problem. None of the predictions shown in Figures 5.2-6 and 5.2-7 can be made with analytical models. The time variations, the leakages, and the viscous losses cannot be easily modeled using closed form solutions. The only tool available for these types of predictions is CFD. Finally, it can be asked which technique is preferred? A system of meshes or an overset mesh. The answer depends on the complexity of the geometry and the information that is needed after the calculations are completed. The overset mesh tends to have a greater accuracy but the labor involved in creating an overset meshes is far greater than the level of effort required to construct a system of meshes.

In summary, CFD provides a time dependent picture of the flow inside turbomachinery. The improvements made in CFD will continue to increase as the cost of making these calculations decreases, the speed of computers increase, and the solver accuracies improve. We have reached a technological turning point – the steep competition between companies to develop quieter and more efficient compressors make CFD predictions increasingly more important each time a new product development effort is launched. When applied for noise prediction, CFD is providing a major tool in designing quieter products for the future.

[2] Inlet cubic feet per minute



(a) (b)

Figure 5.2-2. *Roots Blower and Rotor.*

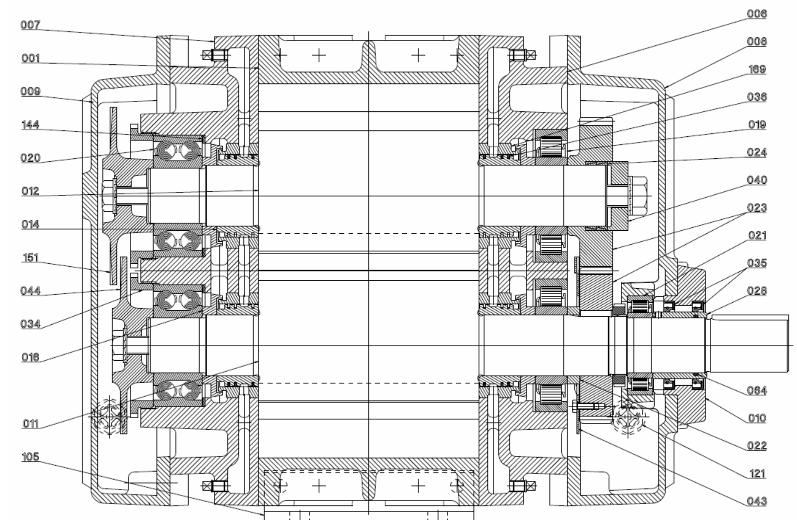
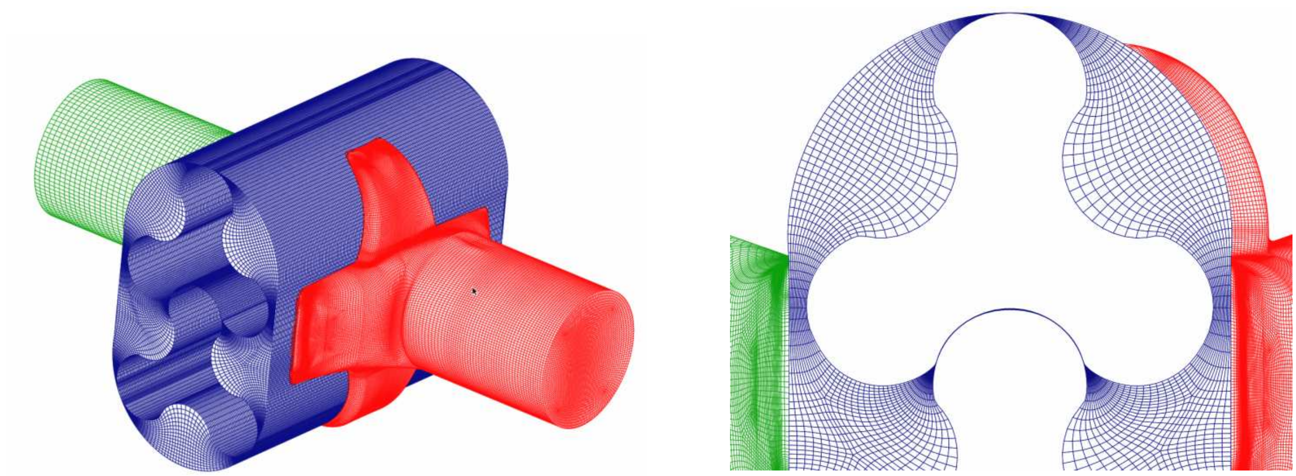
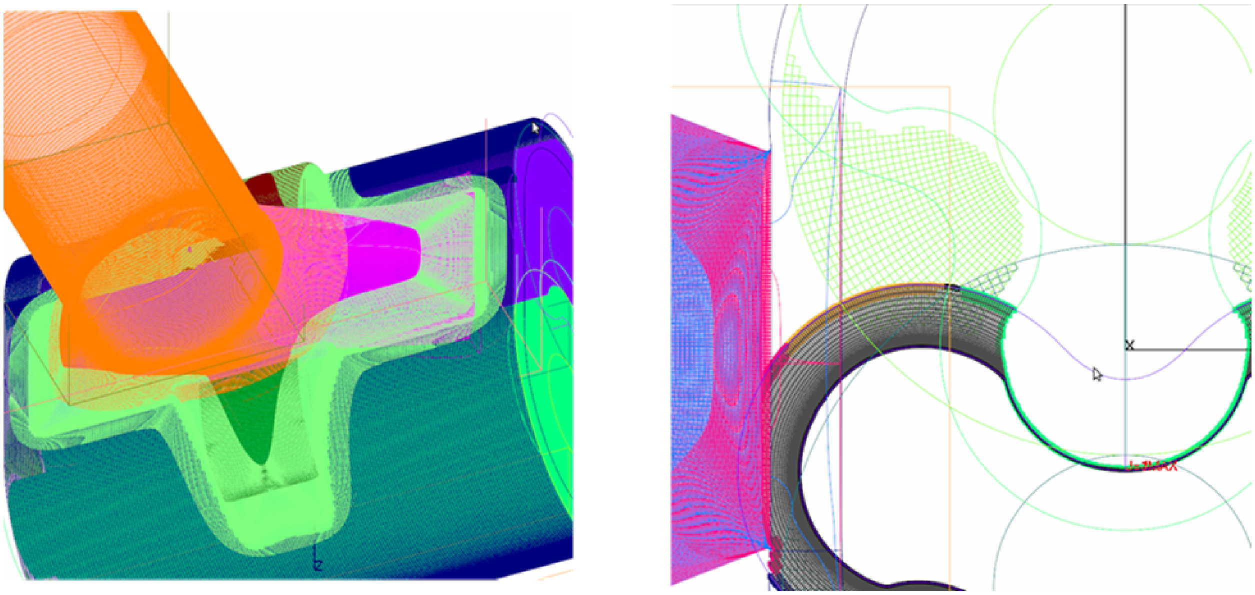


Figure 5.2-3. *Engineering Drawing of Blower.*



(a) (b)

Figure 5.2-4*. System of moving meshes.*



(a) (b)

Figure 5.2-5. *Overset meshes.*

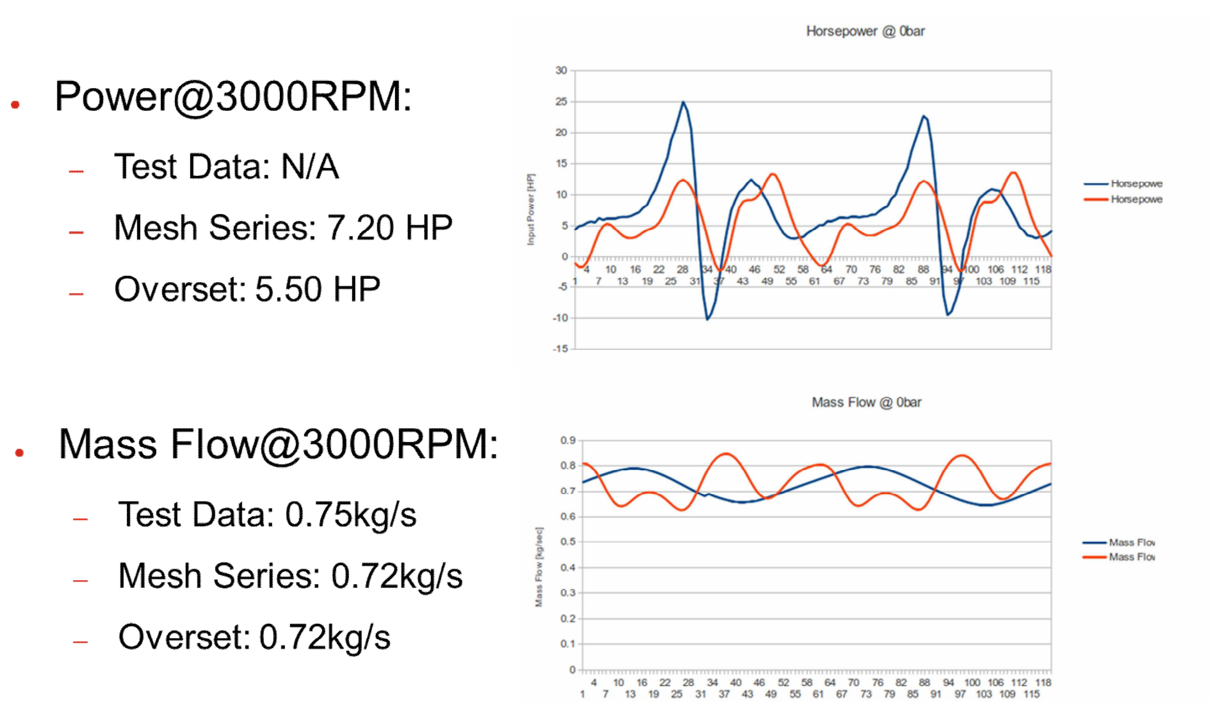


Figure 5.2- 6. *Roots Blower at 0 bar.*

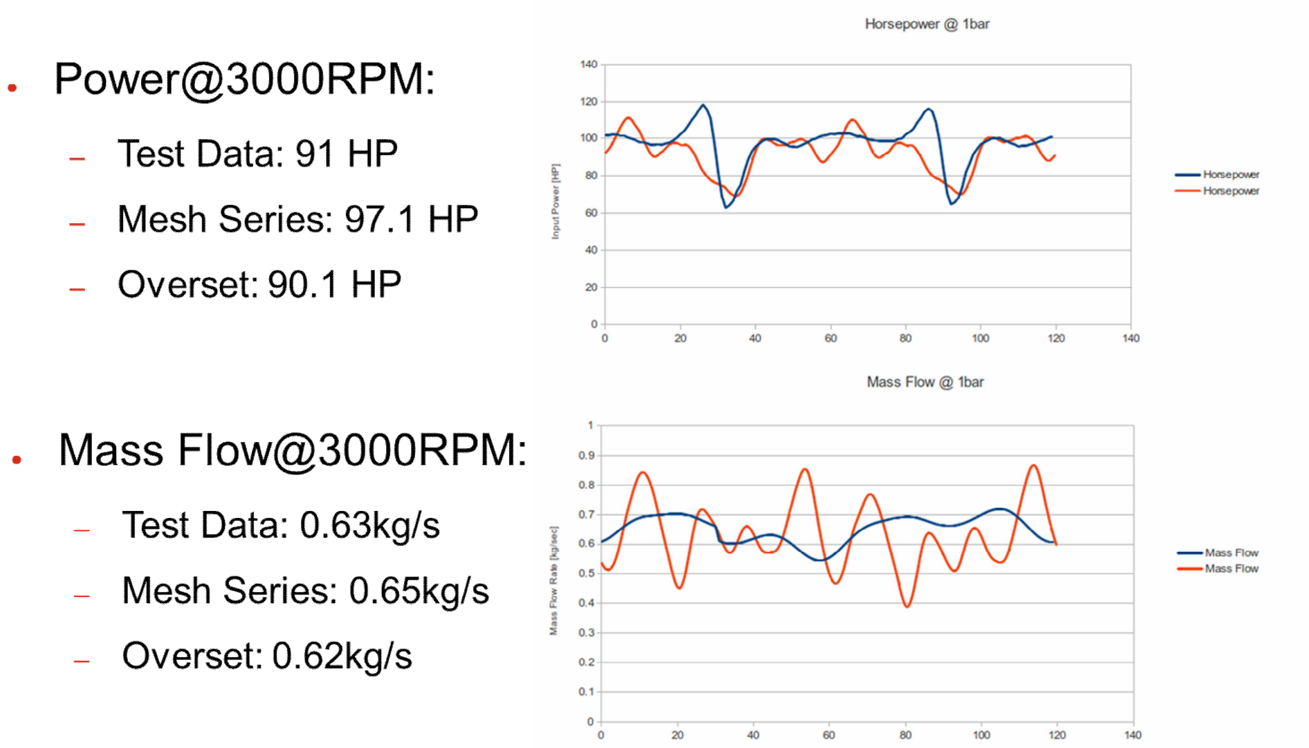


Figure 5.2-7. *Roots blower at 1 bar.*

5.3 Compressors and pneumatic tools

Michael Lucas, Principal Engineer Ingersoll Rand, Davidson, North Carolina

Introduction

New product development teams follow a design process known as "design intent." The engineering process is used to define the form, fit, and function of the new product. Design intent begins with a new product development agreement drawn between the marketing and engineering departments. A new product development agreement contains the product's performance specifications. Key areas of focus in most new product development agreements are the product manufacturing cost, the reliability, power, efficiency, and noise. This paper describes the role of a noise control engineer in a development team. The two topics discussed are (1) the most common noise control techniques used in the compressor industry and (2) how compressors and pneumatic tools are tested for noise.

Noise Control Techniques

Acoustical Enclosures Many compressors are sold with an acoustical enclosure. The enclosure's primary purpose is to reduce the compressor noise to an acceptable level. Compressor enclosure designs vary between manufacturers. One feature that is common to all are the openings in the enclosure to provide for cooling air to remove the heat of compression and also provide cooling air to the drive system and the compressor. Most compressor enclosures have two openings for cooling air to enter and exit the enclosure (see Figure 5.3-1a). Located inside the package enclosure is either a lined duct or parallel baffle silencer.

One variation of an acoustical enclosure design used at Ingersoll-Rand is a two compartment system where the air for the cooling system is contained in a separate compartment from the compressor (see Figure 5.3-1b). The air enters the enclosure from the left. Afterwards the air follows two paths: one path is through the air coolers and the other path is directed through the compressor compartment. The two compartment design isolates the air-end noise from the cooling noise. The result is an overall lower package noise. (patent number US 6447264 B1)

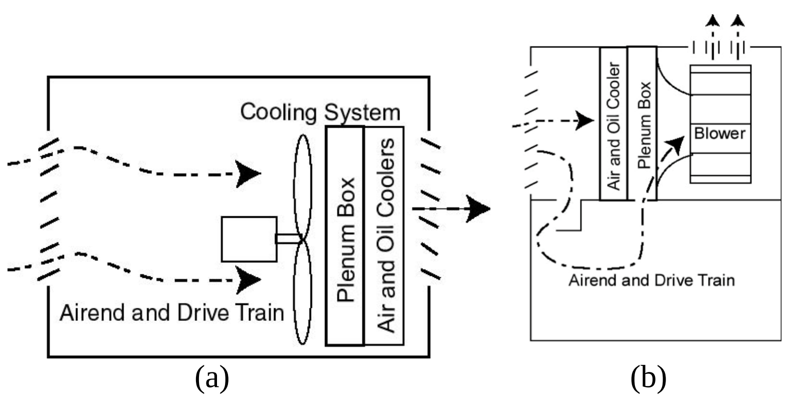


Figure 5.3-1*. Low Noise Acoustical Enclosure designs.*

(a) traditional enclosure design and (b) two compartment enclosure design.

Fan Noise Designing a quiet cooling system is best accomplished using fan selection curves, similar to that shown in Figure 5.3-2. The most common problem in fan selection is finding a fan that satisfies all of the issues surrounding the design intent. Outside factors that enter the decision process are the pressure drop across the fan, the cost of the fan, the fan drive speed, the size of the fan, and the application within the package. All of these factors influence the noise control engineer's decision process and often lead to a decision that is less than optimal for noise.

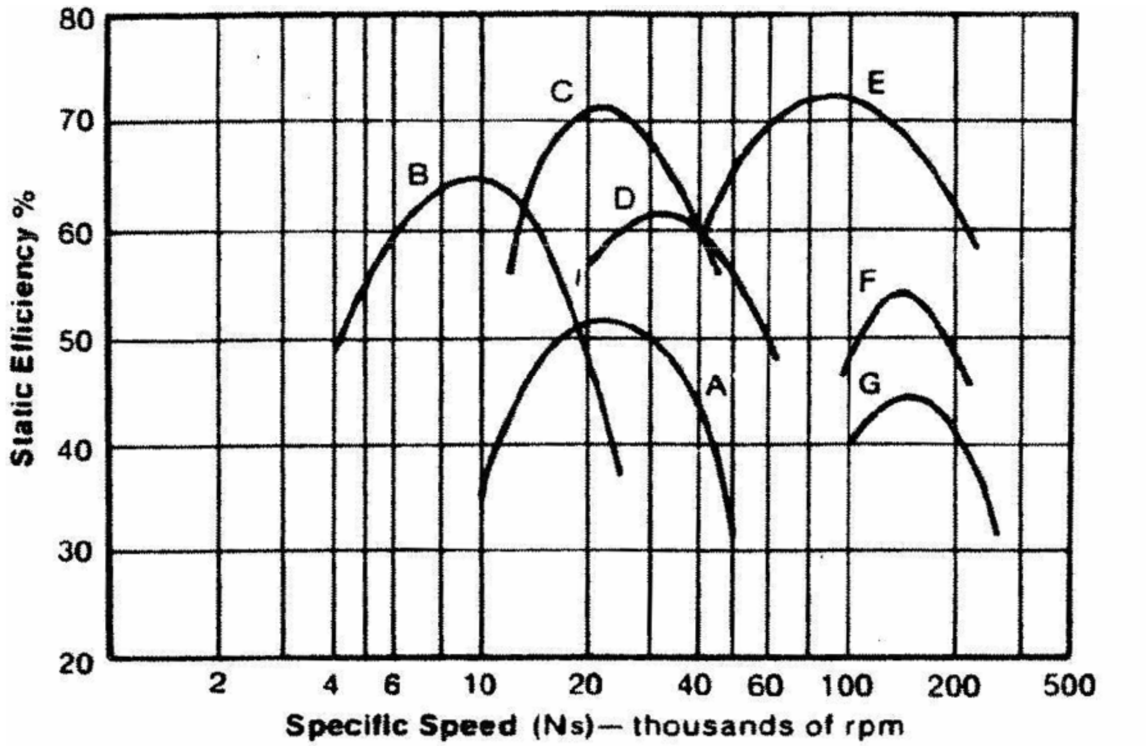
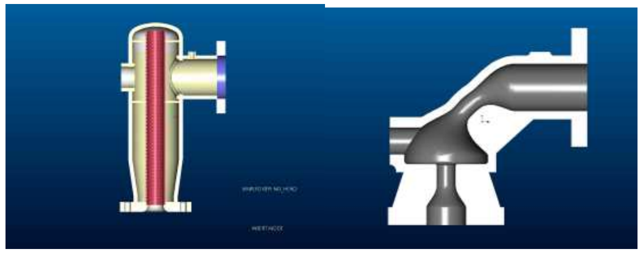


Figure 5.3-2. *Fan Selection Curves.*

Mufflers Mufflers are typically found: at the inlet and outlet of package enclosure openings, at the inlet to the compressor, and in-line with the pressurized piping system. In principle the use is the same for all silencers but the applications vary. One example is a package enclosure silencer. Package enclosures typically use parallel baffles, broken line of sight or a lined duct. A compressor inlet silencer typically uses a lined duct or an inlet filter housing expansion chamber to reduce the inlet noise. At the discharge of the compressor, absorptive or reactive silencers are used to reduce the pressure pulsations. Again any silencer design decision is dependent on the final design intent.

In Figure 5.3-3 is an example of three different types of silencers used to reduce compressor discharge pressure pulsations. All three silencers perform the same function of reducing pulsations. Ingersoll-Rand prefers to use only silencer (b). In silencer (a) the fabricated construction is costly to make. Silencer (c) uses a sound absorptive material that can deteriorate over time.



(a) (b)

(c)

Figure 5.3-3. *Discharge pressure pulsation dampeners (a) perforated tube, (b) reactive, and (c) absorptive.*

Testing Compressors and Pneumatic Tools

Standardized Testing The old test code used by American manufacturers for testing stationary compressors was ANSI S5.1 1971 titled "CAGI-PNEUROP Test Code for the Measurement of Sound From Pneumatic Equipment.[3]" The equivalent European Union test code was PN8NTC2.3, titled "Measurement of Noise Emission from Compressors and Vacuum Pumps.[4]"

Beginning February 2004 ISO 2151,[3] replaced the previous two standards. ISO 2151[5] is very similar to PN8NTC2.3 with the following two exceptions: (1) noise measurements can be made using the hemispherical technique and (2) noise measurements must be declared as the A-weighted sound power level and the measurement uncertainty. The process of measuring the sound power level using pressure microphones is described in ISO 3744.[6] Both the hemispherical and the parallelepiped methods must have a sufficient number of microphones such that the number of microphones used in a test exceeds the difference in decibels between the highest and the lowest sound pressure levels. Most average size industrial compressors require ten microphone positions when using the hemispherical technique and nine microphone positions when using the parallelepiped technique.

[3] *CAGI-PNEUROP Test code for the measurement of sound from pneumatic equipment*, ANSI S5.1 : 1971 Compressed Air and Gas Institute (New York, N.Y., 1969).
[4] Measurement of Noise Emission from Compressors and Vacuum Pumps (Engineering method), PNEUROP PN8NTC2.3, October 1998.
[5] *Acoustics-Noise test code for compressors and vacuum pumps—Engineering Method (Grade 2),* ISO 2151:2004 (International Organization for Standardization, Geneva, Switzerland, 2001).
[6] *Acoustics-Determination of sound power levels of noise sources using sound pressure-Engineering method in an essentially free field over a reflecting plane*, ISO 3744: 1994 (International Organization for Standardization, Geneva, Switzerland, 1994).

The declaration of the noise level as a dual-number is new to the compressor industry. The declared value must be rounded to the nearest decibel and given as the A-weighted sound power level. The measurement uncertainty is declared as +3 dB, unless the manufacturer can prove that the uncertainty statistically differs from 3 dB. Methods are provided in the standard and in the normative references for determining what is referred to in the standard as the k value.

The test code that is used for pneumatic tools is ISO 15744 titled "Hand-Held non-electric power tools- Noise measurement code – Engineering method (grade 2).[7] Both ISO 2151 and ISO 15744 share the same technique for determining sound power using pressure microphones (see ISO 3744). Acoustic intensity is another accepted method for determining sound power both for compressors and pneumatic tools. ISO 9614 part 1[8] and part 2[9] provide the methodology for measuring and reporting the sound power either using the discrete point or the scanning method.

Diagnostic Testing During the design process, engineering prototypes are built and tested for performance and noise. Product noise testing follows the ISO standards previously discussed. Diagnostic testing is performed only when a product noise level exceeds the marketing specification or when there are unusual sounds detected. The three most common techniques used at Ingersoll-Rand to identify a noise source are 1) estimating the noise level using accelerometers, 2) measuring pressure pulsations, and 3) using a scanning microphone array to find noise sources. The first two techniques are used both on compressors and pneumatic tools. A scanning microphone array is only used on a compressor package.

Estimating the noise level using accelerometers is described in ISO 7849.[10] The technique is limited to structure borne noise. The power of this technique allows the noise control engineer to measure individual surfaces of a piece of machinery and then rank the contribution from each individual surface. Table 5.3-1 contains an example summary of a test performed on a centrifugal compressor. Table 5.3-1a shows the individual measurements made on all of the compressor surfaces. At the bottom of the table is the dB summation. For comparison with the Table 5.3-1a results, Table 5.3-1b shows the results when other measurement techniques were applied on the same compressor. The agreement between these techniques is remarkable.

---

[7] Hand-held non-electric power tools – Noise measurement code – Engineering method (grade 2), ISO 15744:2002 (International Organization for Standardization, Geneva, Switzerland, 1994).

[8] Acoustics-Determination of sound power levels of noise sources using sound intensity – Part 1: Measurement at discrete points, ISO 9614-1:1993 (International Organization for Standardization, Geneva, Switzerland, 1993).

[9] *Acoustics-Determination of sound power levels of noise sources using sound intensity – Part 2: Measurement by scanning*, ISO 9614-2:1996 (International Organization for Standardization, Geneva, Switzerland, 1996).

[10] Acoustics -- Determination of airborne sound power levels emitted by machinery using vibration measurement -- Part 2: Engineering method including determination of the adequate radiation factor. ISO/TS 7849-2: 2009. (International Organization for Standardization, Geneva, Switzerland, 2009).

Table 5.3-1. ISO 7849 measurements compared to testing performed using other standards.

Atlas Copco	Sound Power Level (dB)	Sound Power Level (dBA)
First Stage Turbine and Discharge into Cooler	97.4	97.9
First Stage Cooler	92.6	91.6
Air Into Second Stage Turbine	85.4	85.1
Air Out of Second Stage Turbine	96.1	95.3
Second Stage Cooler	91.1	90.6
Air into Third Stage Turbine	86.1	86.2
3rd Stage Turbine	90.8	91.4
3rd Stage Cooler	89.1	89.3
Gearbox	90.1	89.8
Total Sound Power Level Radiated From Compressor	102.2	102.1

(a)

	Sound Pressure Level (dBA)	Sound Power Level (dBA)
Atlas Copco ZHC-6000-6		
CAGI PNEUROP PN8NTC1.2	88.8	
ISO 9614-2	88.8	102.9
ISO 7849TR		102.1
Ingersoll-Rand 3CII		
CAGI PNEUROP PN8NTC1.2	92.3	
ISO 9614-2	90.1	104.6
ISO 7849TR		

(b)

Another technique used to identify noise sources is a scanning array of microphones as shown in Figure 5.3-4. The array is swept along the side of a compressor. A reference microphone and in-house capabilities are used to make holography calculations. Shown in the figures are the pressure contours at the port passing frequency of the compressor.

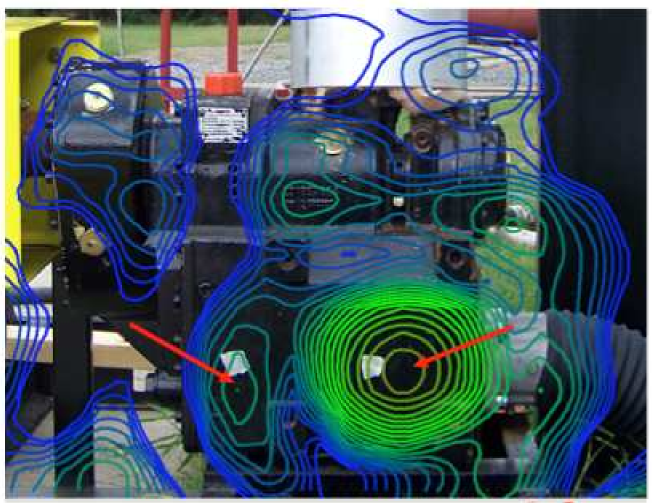


***Figure 5.3-3**. Holographic testing.*

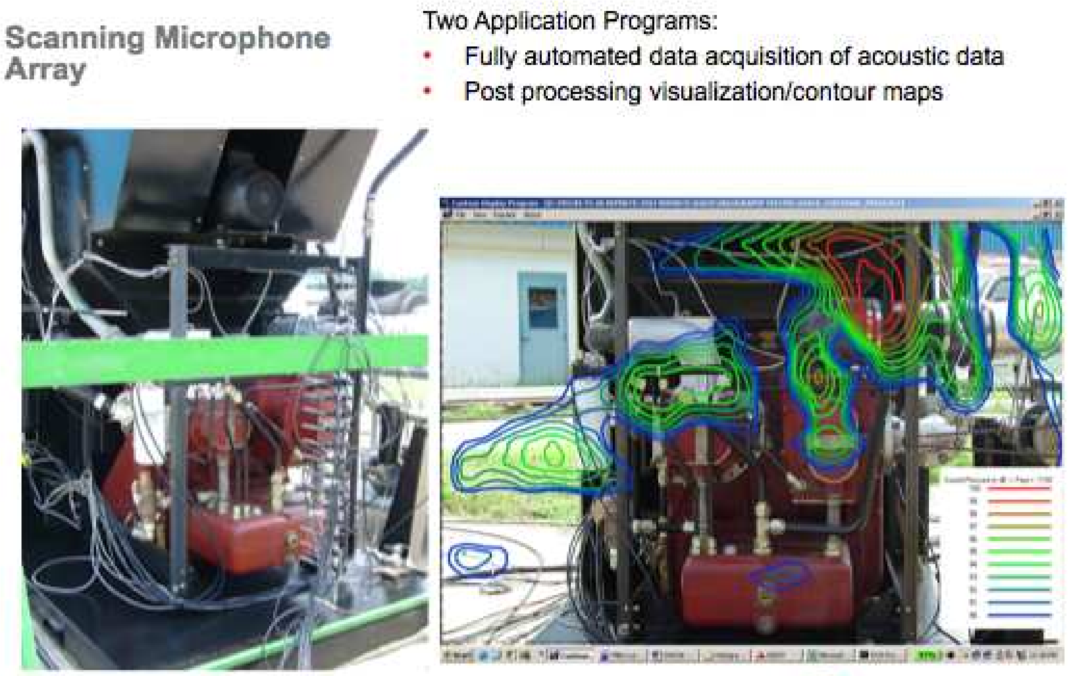


Figure 5.3-4. *Holographic testing.*

Another technique used to identify noise problems are measurements made using dynamic pressure pulsations. For this method the transducers are placed inside the flow path at various points of interest. Over time, an understanding has been developed of acceptable pressure pulsations from those that are not. When a problem is identified then CFD modeling and prediction often becomes one of the tools used to further understand the cause of the pulsations.

In closing, it is critical that a noise control engineer is involved in all aspects of a new product design team. The noise control engineer can provide direction and understanding of how to design a new product early in the design phase thereby avoiding the building and testing of a product that has unacceptable noise levels. Incorporating technological advances and capabilities has enhanced new product development efforts. In addition, this approach has provided success in achieving the design goal of producing a reduced noise as well as a more efficient product.

5.4 Engineering controls for reduction of industrial noise exposures

Robert R. Anderson, Principal, Anderson Consulting Associates

Robert Anderson reviewed a series of fundamental issues surrounding noise control in industry. Table 5.4-1 suggests factors that influence noise control decisions at established heavy manufacturers and at newer, "green technology" manufacturers (for example, solar panel manufacturers or online retailers). The size of the company plays a role as well.
Larger, established manufacturers consider unions and costs when making noise-control decisions. Small firms are driven mainly by costs and rarely have formal noise-control programs, such as Buy-Quiet,[11] in place. Conversely, newer green manufacturers are more likely to have programs to address noise emissions from both existing and new equipment. For example, retrofit noise controls are not a program emphasis at small heavy manufacturing plants but are a program emphasis at green technology manufacturing plants.

Table 5.4-1. Drivers of noise controls.

Type of Manufacturing	Size of Company	Influencing Factors	Program Emphasis	
			Buy Quiet	Retro-fit
Established Heavy Manufacturing	Large	Control Costs, Unions, Compliance, Medical Costs	Yes	Minimal
	Small	Control Costs, Compliance	No	No
Green Technology Manufacturing	Large	Workplace Conditions, Global Uniformity /Compliance, Medical Costs	Yes	Yes
	Small	Workplace Conditions, Compliance, Medical Costs	Yes	Yes

When purchasing new equipment, manufacturers are influenced by several noise-related factors. Examples include:

- Does not increase noise levels in the work environment
- Avoid the costs of more expensive retrofit noise controls
- Noise controls often also control hazards such as oil mist and metal working fluids
- Low-noise hand tools often offer ergonomic benefits, as well

[11] http://www.cdc.gov/niosh/topics/buyquiet/

- Equipment with built-in noise controls often also incorporate improved process efficiencies and improved product quality
- Avoid potential penalties to production and maintenance
- Supplier knowledge supplements in-house noise control expertise

As manufacturers adopt new technologies, particularly in the automotive industry where Anderson has done much of his consulting, plants are becoming more automated. When robots handle some of the hands-on processes, workers become process monitors rather than hands-on line operators, and are able to work further from the noise sources. Also, robots handle and move parts with great precision, reducing part impact noises.

The introduction of new technologies is also influencing relationships between manufacturers and their suppliers. Manufacturers form collaborative partnerships with certain trusted suppliers to utilize their expertise in planning new design initiatives and alternative processes. This leads to better efficiencies and lower noise.

Anderson provided examples of noise control successes within the automotive industry, where equipment is turned over frequently.

In machining operations of large metal parts, equipment is made quieter mainly through total enclosures, as shown in Figure 5.4-1. Total enclosures successfully address noise, oil mist, and safety guarding. Process operating noise levels have been reduced from greater than 90 dB(A) from tooling functions and chatter to less than 80 dB(A) measured at one meter.

Figure 5.4-1. *Examples of Enclosures for Machining Operations.*

Large metal stamping is traditionally a noisy manufacturing operation. Industry is now turning towards transfer presses, a single unit containing a number of presses, where noise can be readily controlled by a total enclosure, such as shown in Figure 5.4-2. These robust enclosures are being used in Europe and are designed to allow dies and tooling to be changed quickly, often several times per shift.

Figure 5.4-2. *Metal stamping operations move to fully enclosed units.*

Assembly cells commonly used in body shops and assembly weld areas have changed from pneumatic drives to servomotor drives. This has added precision to the process by controlling speeds, resulting in reduced weld tip impacts, extended tip life, and energy savings. In addition, the new weld cells require less maintenance than conventional pneumatic drives. Noise levels, which were typically in the range of 85 to 90 dB(A) are now less than 80 dB(A) in many cases.

Within the auto industry, most pneumatic hand tools have been replaced with electric tools in assembly plants. Also, noisy impact wrenches have been replaced with impulse tools and stall-torque tools. This change brings with it both less noise and ergonomic benefits.

Reducing the noise associated with compressed air is receiving attention in most industries. Old nozzles are being replaced with new low-noise nozzles and companies are implementing programs for controlling air leaks and air exhausts. This is achieving both less noise and lower plant operating costs. Examples of commercially available controls for compressed air noise are shown in Figure 5.4-3.

While improvements are being implemented throughout the auto industry, certain noise sources remain. The most severe are due to compliance requirements from crash testing standards and quality standards of spot welds. Pneumatic chipping hammers used to destroy car body welds during the testing process produce noise levels in excess of 110 dB(A). Metal stamping operations continue to pose significant challenges for the noise control engineer.

The tooling component is a principal source of noise during metal stamping operations. Techniques have been developed to address the tooling noise but have not been consistently carried forward as die design and building are contracted to overseas companies. Some significant benefits can be expected when these measures and stricter die design procedures are reincorporated into die standards. Ejection of parts and scrap is a secondary source of noise during press operation.

Figure 5.4-3. *Commercially available controls for compressed air noise.*

One obstacle to increasing the availability of low-noise equipment is the lack of engineering noise control design experience within some supplier organizations. This has sometimes led to the misapplication of common noise control treatments. A common example is the use of sound-absorptive open-cell foam materials without including a proper protective outer surface layer. Open-cell foams are easy to cut to shape and install, which makes them popular. But unprotected, absorptive material will deteriorate rapidly in a harsh industrial environment and will wick-up oils leading to a fire hazard.

Both manufacturers that want to purchase reduced-noise equipment and suppliers interested in selling such equipment can find guidance in a technical report sponsored by the Association for Manufacturing Technology, ANSI Technical Report for Machines: Sound Level Measurement Guidelines, B11.TR5-2006. The document updates a 1970s report. It specifies measurement procedures to determine noise emissions of equipment under as-installed full operating conditions. The specified noise emission level is determined by the end-user. The default value has traditionally been an ambient-corrected 80 dB(A) L_{eq} at 1 meter, but some companies have chosen to use 77 dB(A).

Anderson described the outcomes of Buy-Quiet programs initiated at two automotive companies more than 30 years ago. In 1996 the companies reported that 12 percent to 18 percent of their workforces were exposed to noise levels greater than 90 dB(A). Sixteen years later, in 2012, noise exposure had been significantly reduced to 1 percent to 5 percent of their workforces. He offered the following conclusions about engineering controls for reduction of industrial noise exposures:

- Commercial and process noise controls are available in most new manufacturing equipment installations. Quieter process alternatives are also available.

- The most cost-effective means to reduce noise exposure is through a Buy-Quiet program.
- Especially in retrofit noise reduction applications, cost is a major consideration. This may be due to the fact that individual operating locations have to pay for the controls, while in larger companies the cost of controls in new equipment is covered under project funds.
- The enforcement priorities of the Hearing Conservation Amendment,[12] which permit the use of hearing protection and medical surveillance as a means to compliance over engineering controls, (given that the HCP is less expensive and equally effective) is a reason that retrofit activity is weak.
- There is a serious lack of expertise in noise control engineering within the supplier and end-user base.

Anderson concluded by calling for three things:

- Make the case for the added value of low-noise products.
- A Buy-Quiet program must be an element of a noise control engineering program for compliance with 29CFR 1910.95.[13]
- Enhance supplier and end-user awareness and expertise through technical training in measurement and control fundamentals.

[12] Suter AH. "The hearing conservation amendment: 25 years later." Noise Health. 2009 Jan-Mar;11(42):2-. PMID:19265247
https://www.osha.gov/pls/oshaweb/owadisp.show_document?p_table=STANDARDS&p_id=9735

5.5 Examples of noise control technology available for manufacturing equipment

James D. Barnes, senior engineer, Acentech Incorporated. Cambridge, Massachusetts

In the mid-1970s, within the source – path – receiver model for evaluating noise problems, the focus was mainly on path control, adding traditional barriers, such as mufflers and enclosures. Some effort focused on the receiver, trying to move the worker away from the area where the noise was being produced. Controlling noise from the source end involved maintenance, replacing machines, or retrofitting. Cost information was most easily obtained for path controls because supplier costs were obtainable and could be applied to deciding how much a certain noise reduction would be used within a particular industry. Predicting costs for source control, on the other hand, was challenging because some of the approaches were proprietary. Estimating costs for source controls was also challenging.

Today is a different story because of the noise control pioneers at INCE/USA, who pushed for noise regulations in particular products. The Environmental Protection Agency (EPA) regulated the noise emissions of portable air compressors. In response to demand from Europe and more recently the United States, today's portable air compressors have incorporated some excellent noise control designs. Newer lines of portable compressors have incorporated enclosures or whole processes located apart from the worker, so that the worker becomes more of a monitor than an operator. Much of this technology was first developed for the military and is now migrating to industrial and commercial marketplaces.

Some of the technologies available today for noise reduction include:

- Reduced-speed low-noise fans. The Chrysler K car, for example, added quieter radiator fans.
- Quieter high-efficiency motors. The U.S. Navy needed quieter submarines and ships, so high-efficiency motors were developed, which reduced noise and saved money in the long run.
- Quieter gearboxes were developed for the U.S. Navy as well, for quieter ships and submarines. The techniques used to design and manufacture quieter gear boxes have migrated into other industrial products.
- Direct drive replacing gearboxes and drive shafts. In some cases, gear boxes are being replaced completely with direct drive systems, eliminating gear noise.
- Variable frequency drive (VFD) systems with well-matched motors. Rather than having the machine operating a fan or a pump operating at its maximum speed, VFD systems can run at reduced speed and noise which also reduces energy. In the past, motors have not been well matched and have been substantially noisier than standard motors.
- Rotary replacing reciprocal. When work is only happening in one direction, it's like a ship being fully loaded with cargo, during one leg of its trip, but empty on the way back. Rotary equipment does work during the whole cycle. Inherently, they can be higher speed with higher throughput, less impact sounds, and less wear and tear on the equipment.
- Local area communication networks enable industry to do away with P/A systems.
- Conserve air to be quieter and cheaper.

An example from Michael Lucas of noise control technology was a waterknife (Figure 5.5-1 purchased under a "Buy-Quiet" program at NASA's Glenn Research Center machine shop in Cleveland. It was more than 30 dB quieter than an older waterknife in the same work area.

The manufacturer designed it to be quiet by changing the noise source mechanism, not by applying any after-the-fact noise control treatment or materials.

Figure 5.5-1. *A waterknife designed to be 30 dB(A) quieter than an older version.*

The manufacturer of the diesel generator in the Glenn Research Center’s (GRC) Central Air Equipment Building met the noise emissions specifications by enclosing the nominal (“loud”) model in an on-skid enclosure shown in Figure 5.5.2 that provided the required amount of sound attenuation. Manufacturer-supplied enclosures or other controls are specifically designed for a particular piece of equipment. They are far superior to retrofit enclosures or other do-it-yourself designs because they will provide the rated attenuation while also providing proper ventilation and convenient access for maintenance.

Barnes offered his view of the future. He expects to see continued active noise control along with an increased emphasis on robots and other extreme automation to protect the receiver. Finally, 3-D printing, is a completely different approach to production that will reduce noise at the source by removing the metal that needs to be cut down. Instead of cutting down or removing material, 3-D printing builds up the product. It won’t likely displace high-volume production, but for low-volume production it could be useful and quieter.

Figure 5.5.2. *Example of a manufacturer-supplied noise control enclosure on a diesel generator.*

5.6 Advanced acoustics for quiet power generator sets

Shashikant More, Technical Specialist, Mechanical Engineer, Cummins Power Generation

Shashikant More described his opinions about the ongoing efforts at Cummins Power Generation to develop and make available to customers reduced-noise power generation sets (Gensets) for use at their facilities. He addressed applicable noise standards and regulations, component noise sources for Gensets, specific noise control treatments, installation considerations, and the hemi-anechoic chamber at the Acoustical Testing Center at Cummins.

Figure 5.6-1 illustrates the architecture of a typical Genset installed within a noise control enclosure. It shows the necessary noise abatement treatments including cooling air inlet and outlet mufflers, a well-sealed enclosure with interior sound absorptive lining, a high-performance engine exhaust muffler, and vibration isolation between the Genset and the enclosure.

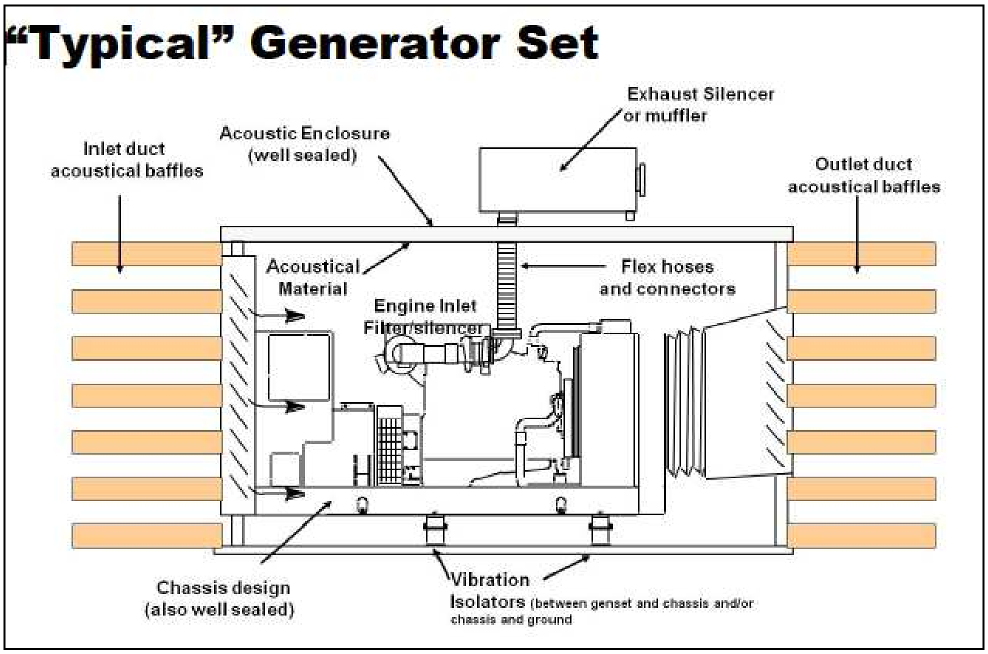


Figure 5.6-1. *Representative sketch of a typical Genset layout.*

Table 5.6-1 lists the principal Genset noise sources, the noise paths from the Genset, and representative noise receivers. The four principal noise sources include the engine casing, the engine exhaust, the alternator, and the radiator cooling fans. There are airborne and structure borne noise paths, both of which must be addressed properly in the design and production of low-noise Genset packages. Noise receivers can include nearby people, buildings, or animals.

Table 5.6-1. Typical genset noise sources, paths, and receivers

Noise Sources: Engine, Exhaust, Radiator Fan, several minor contributors
Noise Path: Airborne or Structure-borne
Noise Receivers: Humans, Animals, Structures

The diagram in Figure 5.6-2 illustrates relationships between noise sources, transmission paths, radiating surfaces, and noise treatments for a typical enclosed Genset. Vibration isolators are shown between the engine/generator and the chassis and enclosure. For sensitive locations, vibration isolators can also be required between the Genset and the supporting floor structure. Sound absorptive materials (well protected) are shown within the enclosure. The engine combustion-air inlet includes a filter and muffler. The engine exhaust includes a muffler located inside or above the enclosure. The exhaust muffler can be selected as industrial grade, residential grade, critical, or super critical grade depending on the application. The ventilation air inlets and outlets include duct liners or mufflers. These mufflers are often of the parallel baffle type. Flexible connectors are shown for hoses and cables to reduce vibration transmission to enclosure panels. Leaks out from the enclosure compartment are well sealed or eliminated when possible. The design of the enclosure panels includes consideration of mass, stiffness, and vibration damping so as to increase sound transmission loss and reduce noise radiation.

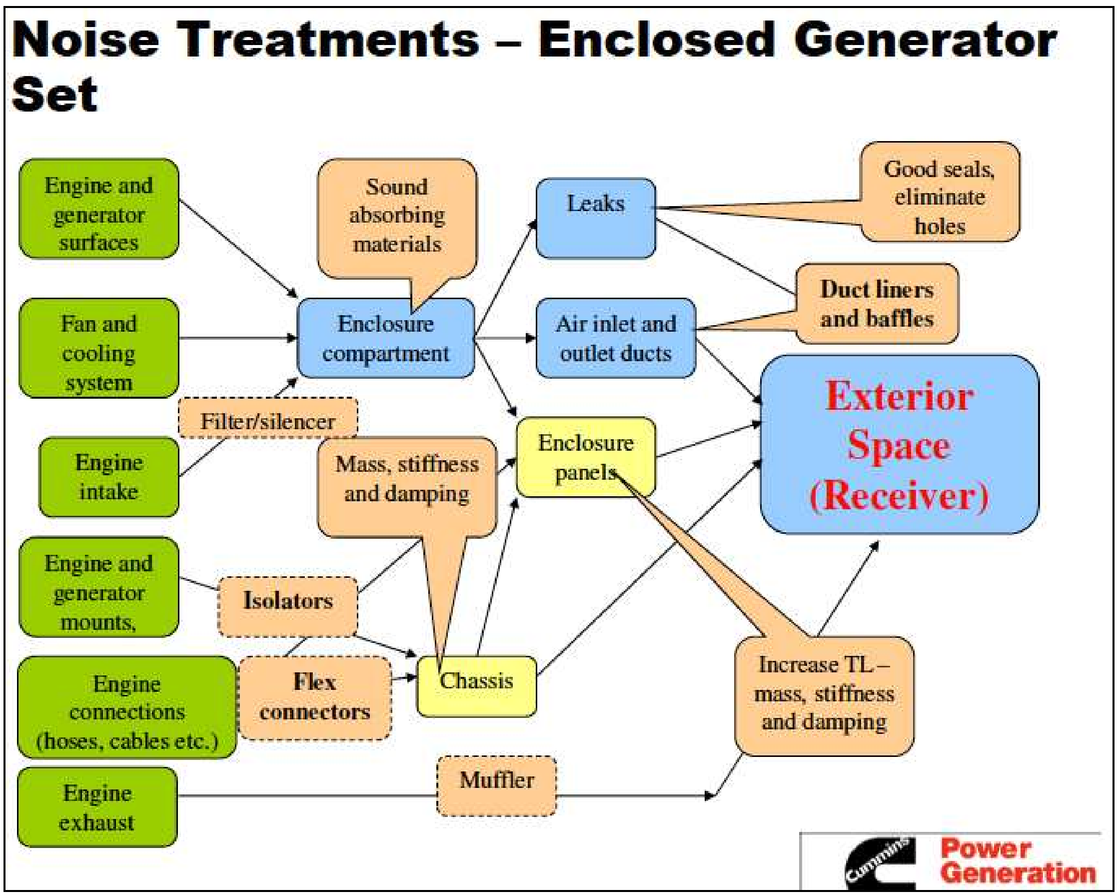


Figure 5.6-2. Diagram of representative noise treatments for a typical enclosed genset.

Genset fuel types include diesel, natural gas, gasoline, and propane. Power ratings range from standby service, prime, and continuous operation. Figure 5.6-3 shows a well-enclosed and muffled Genset located in an industrial location.

Figure 5.6-3. *Genset with effective noise control package.*

Noise levels as low as 75 dB(A) at one-meter are now available for mid-size gensets in the 800 kW rated capacity range. They provide reduced noise levels for on-site work areas as well as for off-site noise-sensitive neighbors.

5.7 The FRITA[14] project: reducing noise and improving safety

Rebecca R. Taylor, Senior Vice President**,** National Center for Manufacturing Sciences

The National Center for Manufacturing Sciences (NCMS) is a private, not-for-profit technology development organization that brings together manufacturers, governments, and universities to collaborate on technology development for manufacturing. Rebecca Taylor described how a single technology improvement project can be a model for future solution-oriented collaborations within tomorrow's manufacturing environment. The project, FRITA, involved dealing with the challenging task of removing more than 10,000 high-strength rivets during maintenance of an advanced F-22 Raptor jet aircraft.

Aircraft fuselage panel removal is sometimes necessary to gain access for interior inspections and maintenance. To remove the panels, the aluminum or titanium rivets that hold the panels in place must be removed.

Rivet removal is often performed with hand-held drills, a time-consuming process (each heavy-duty fastener can take 3 to 10 minutes to remove) that involves operator exposure to noise and metal shavings that can become lodged in the airplane's delicate subsystems as well as workers' eyes, skin, and clothes. Ergonomic stress is also a common injury for rivet removal workers, who must apply heavy pressure when drilling the rivets and often need to reach into awkward locations on the plane. Also, even with well-trained workers, manual drills will sometimes slip and cause damage to the aircraft. Damage is unavoidable and costly.

The Department of Defense requested assistance from NCMS to form a collaborative team to solve rivet removal problems. In response, NCMS assembled a team of small tech providers, large aircraft manufacturers, the Army, Navy, and Air Force. NCMS experience demonstrates that successful technology improvements are often found at small and mid-size firms. An NCMS member company, Perfect Point, was working on a new tool, a handheld electrical discharge e-Drill, which held promise in solving the problem. The e•Drill was easy to operate, faster than standard drills, almost error-free, automatically clears metal debris, stops cutting at the end of the rivet, and is much quieter than conventional drills. Figure 5.7-1 shows the impact of the improved process on rivet removal at two DOD locations and a commercial firm.

[14] Fastener Removal Improvement Technology Adoption

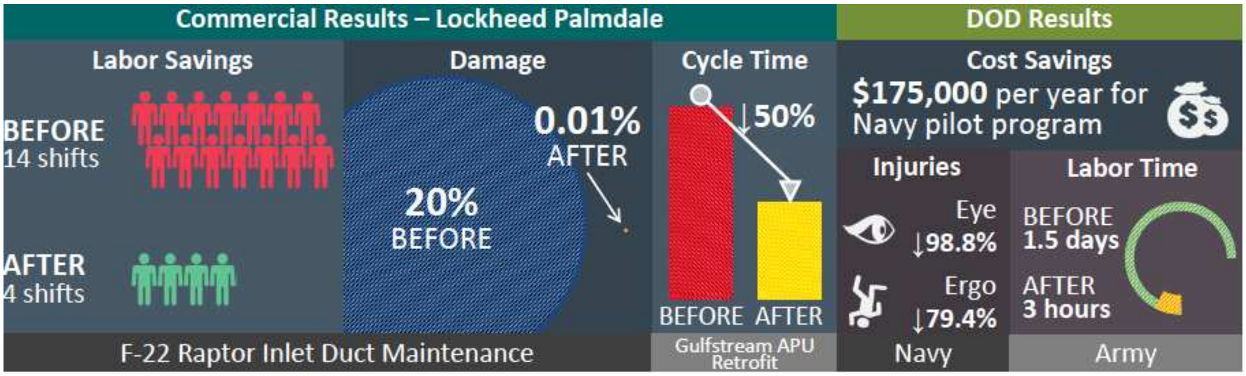


Figure 5.7-1. *The impact of new rivet removal process at Lockheed Palmdale and Department of Defense.*

This small company now has a new-technology proven product that it can sell to organizations in need, which goes beyond aircraft manufacturers and users. The lesson here from 10,000 rivets is that noise control and technology benefits can be achieved through collaboration and communicating with people in various professions. Taylor's message about the future of manufacturers included:

- Priorities are changing
- Safety is more important than ever
- Optimization is the watchword
- See and improve the whole system – not just the symptoms
- Virtualization will drive new thinking and new solutions

The following descriptions were obtained following the workshop. The e•Drill described in this presentation[15] represents a handheld EDM (Electro Discharge Machining) process. The operator aligns the e•Drill to the target fastener. A spring-loaded center ground pin makes contact with the fastener head. During cutting, the electrode advances and the spark erodes a circular cut groove into the fastener head. De-ionized water is applied to flush the cut zone, keeping the part cool and removing cut debris. Once the cut is complete, the remaining metal fillet is punched out. Information from Perfect Point about the e•Drill is available at its website: http://www.ppedm.com/.

For workers using a conventional drill to remove rivets, noise is radiated from the drill, the cutting tool, and vibration of nearby fuselage panels. The e•Drill produces minimal noise during the rivet removal process.

Provided here is a photograph, from the Point Perfect website, of the e•Drill discussed in this report.

15 Information in this report does not imply endorsement of the e•Drill.

5.8 Changing reciprocating to rotary equipment at a candy plant

James D. Barnes, senior engineer, Acentech Incorporated, Cambridge, Massachusetts

James Barnes described his experience reducing noise at an old-line candy plant interested in improving its processes. The company had the benefit of some very talented engineers and fabricators within the company, and they built their own equipment. As a result, the equipment was a source of pride for all of the employees, but, in time, the equipment became old and had reached the limits of productivity. In addition, worn parts required custom-made replacements. With significant amounts of down time, it became very expensive to operate. It was also noisy.

In summary, the equipment, mainly reciprocating equipment using back-and-forth motions for production, was worn out and ready to be replaced. The company's leadership was ready to make a leap in productivity.

They replaced old pick-and-place equipment with the modern equipment shown in Figure 5.8-1. They also replaced old wrapper machines with a modern rotary wrapper in which a wheel carries the product up where it is wrapped and then dropped into a trough and put into a bagger. This is illustrated in Figure 5.8-2.

Figure 5.8-1. *Modern pick and place equipment.*

Figure 5.8-2. *A modern rotary wrapper machine.*

They also purchased a rotary unscrambler unit that loads bottles into the machine and a bag-filling machine that uses a rotary operation to bring loose nuts in, bag them, and move them out. A rotary unscrambler unit is shown in Figure 5.8-3.

Figure 5.8-3. *Rotary pocket unscrambler.*

The company retrofitted some of the existing equipment as well. One example is called a scrap demolder. After the chocolate is poured into the mold, the mold is moved along a conveyor line. At the end of the line, after the chocolate was picked out of the mold, there was leftover chocolate around the mold. They were using a noisy vibrating mechanism to remove the excess chocolate scraps. They retrofitted an acoustical enclosure that reduced noise while allowing easy access for cleaning.

These changes allowed the candy company to implement several positive design changes:

- Replaced original equipment where possible with rotary equipment.
- Increased production rate significantly with less maintenance, downtime, and noise.
- Additional noise reduction achieved by installing well-designed enclosures and room treatment.

This is one example of an industrial company which recognized the need to modernize and replace old equipment with equipment that was of modern design, was more reliable and productive than the old equipment, and, because of the design, made less noise. It is a good example of a company which invested in its future.

6

The Manufacturing Workplace of the Future

The presentations in this chapter focus on the workplace of the future and efforts to support the U.S. workplace. Noise control is not a core topic in most articles. Opportunities may exist to incorporate noise control efforts as part of these forward-looking programs to support manufacturing.

6.1 The NAE Program Related to Future Manufacturing

Kate Whitefoot, Senior Program Officer for Manufacturing, Design, and Innovation, National Academy of Engineering

The National Academy of Engineering (NAE) has a long history of working on manufacturing issues. In the recent past, the 1980s and 1990s, the focus was U.S.-based competition against other countries to improve productivity across manufacturing and optimize systems to reduce cost. Today, the biggest concern is generating new demand for new products and services coming out of U.S. manufacturing and improving job opportunities across the United States.

The NAE recently launched an initiative on manufacturing design and innovation that looked broadly from R&D through design through the factory floor and integration of software and services that are increasingly being combined with physical products. An expert committee came together to frame the issues, in response to a national dialogue on how to improve the capacity for manufacturing across the United States. The 2012 workshop report, "Making Value: Integrating Manufacturing, Design, and Innovation to Thrive in the Changing Global Economy," is available at www.nap.edu/catalog/13504.

Important themes from the workshop focused on 1) the decline of manufacturing employment, which is occuring as productivity increases. The U.S. is producing more with fewer workers. 2) The traditional lines between manufacturing and services are becoming blurred as manufacturers are increasingly producing services along with their physical products, generating revenue across different manufacturing domains. 3) The nature of the work on the factory floor and throughout the manufacturing chain has tranformed due to a combination of advancing technologies and business processes. Advances in materials science, robotics and advanced sensors, together with increasing speed of product development schedules and integration of software and services all play a role. 4) Many U.S. companies would benefit from upgraded practices. There are many opportunities to generate more innovation and boost job growth.

As a next step, the NAE in the fall of 2013 launched a study called "Making Value for America" with three goals:

- Synthesize a set of best business practices for value creation and implications for the United States.
- Identify educational approaches to prepare the current and future workforce.
- Provide policy and other recommendations to create an effective “ecosystem” for the value chain.

In the factory of the future, continuing advances in technologies and computer power will drive change on the factory floor. It will change the nature of what factory workers are doing.

Workers will need more education and new skills to work with advancing technologies. And these new technologies and tools will be used equally around the world.

References

Design and Analysis of Integrated Manufacturing Systems. NAE. National Academies Press, Washington, DC, 1988.

Making Things: 21st Century Manufacturing and Design. NAE. National Academies Press, Washington, DC, 2012.

Making Value: Integrating Manufacturing, Design, and Innovation to Thrive in the Changing Global Economy. NAE. National Academies Press, Washington, DC, 2012.

Manufacturing Systems: Foundations of World Class Practice. NAE. National Academies Press, Washington, DC, 1992.

6.2 MEP Next Generation Strategy and the Future of Manufacturing

Daniel Lilley, Regional Manager for Strategic Transition, National Institute of Standards and Technology

The Manufacturing Extension Partnership (MEP), a program of the National Institute of Standards and Technology (NIST), is a catalyst for strengthening American manufacturing by accelerating its ongoing transformation into a more efficient and powerful engine of innovation that drives economic growth and job creation. MEP serves as a strategic advisor to promote business growth and connect manufacturers to public and private resources essential for increased competitiveness and profitability. The program is similar to the agricultural extension model, in which experts are located within communities to offer assistance.

The MEP began in 1988. By 1996, MEP had one center in every state and Puerto Rico. The program has about 1,200 state and private consultants, plus more than 2,100 third-party service providers. Projects are run as partnerships through cooperative agreements that are funded one-third from the federal government and two-thirds from state or local resources and industry. In other words, industry pays a fee for the service. The program started because of identified "market failures" in access to information, technical expertise, and cost management.

The face of manufacturing is changing. Business is getting smaller; it needs to get smarter.

The Facts about Small Manufacturers:

- They represent 99 percent of all manufacturing establishments
- They employ 10.2 million people—70 percent of all manufacturing employment
- They are about 57 percent of the total value-added by all U.S. manufacturers

The Challenges for Small Manufacturers:

- Productivity among large firms continues to increase at a faster rate than for small firms
- Market failures occur in several dimensions: firm, inter-firm, consulting/services, public failure

To support small businesses, MEP migrated from the idea of technology transfer to working on issues that are more operational- and productivity-focused, such as plant layout, lean manufacturing, ISO registrations,[1] and quality issues. To be in business at all, a company needs to be lean and highly productive. So today's challenge has moved to innovation and new products and new markets. Small manufacturers have not kept pace on productivity with large manufacturers. They don't have the resources to make the developments and the capital investments or to train the workforce. They are at a disadvantage to large companies (with 500 or more employees).

MEP's next-generation strategy focuses on issues of supply chain, workforce, sustainability, and continuous improvement. The aim is profitable manufacturing growth with an emphasis on the word "profitable" because companies can grow. But it doesn't mean they're going to have sustainability if they can't constantly reinvest in themselves and stay viable financially.

In closing, Lilley listed his view of the future of U.S. manufacturing.

[1] International Organization for Standardization; www.iso.org

- Higher productivity across all sectors
- Productivity growth higher for large versus small manufacturers
- Job growth rate driven by new products, new markets, new customers, exports, embedded technology, and advanced features and benefits
- Gradual increase in additive manufacturing (low volume now; higher volume and greater material content in the future)
- Innovation drive by R&D (private/public)
- Level of direct public/private investment will be challenging
- Market drivers: defense, healthcare, energy, transportation, environment
- Workforce: skills development, leadership, processes, funding
- Materials and process development/applications

6.3 You Could Eat Off This Floor (But Why?): Tomorrow's Industrial Spaces

Rebecca R. Taylor, Senior Vice President, National Center for Manufacturing Sciences

Rebecca Taylor offered a view of the future of manufacturing from the perspective of the National Center for Manufacturing Sciences. The organization is a private, not-for-profit technology development organization that brings together manufacturers, governments, and universities to collaborate on technology development for manufacturing.

It's hard to know what the future of manufacturing will look like. But it's not what many imagine it to be. In February 2013, for example, Dr. Rebecca Blank, acting Secretary of Commerce visited the BMW plant in Spartansburg, South Carolina. Impressed by the spotless facility, she remarked that she could eat her lunch off of the factory floor. Her hosts replied that she could, but they wouldn't let her, because it would dirty their floor.

The mental image of manufacturing as a dirty, tedious job done in unpleasant conditions is hard to break and it interferes with our perception of tomorrow's factory. But how has manufacturing *really* changed? What's different about factories and the things that are being made? What do people understand about manufacturing today's complicated parts like CPUs?

More importantly, what's different in what people accept? The speed of innovation is increasing exponentially and people adapt to new things faster than ever. Time isn't speeding up, we are. That relates directly to the factory of the future. As innovation speeds up, the public perception of manufacturing will change and that may draw more educated workers out of the traditionally appealing careers, such as medicine, into a changed manufacturing environment.

Manufacturing processes are improving, but there will always be limits. Until the fundamental process changes, some manufacturing activities will always be loud, hot, or dirty. Take stamping, for example. How quiet can stamping really get?

The *process* of stamping was probably no louder 50 or 100 years ago. But its impact has been reduced in other ways. Workers are further from the equipment; their ears are protected by mandated safety equipment, and so on. Perhaps the equipment is still loud, but its impact is lessened. And past improvements give reason to believe that even more can be accomplished.

Certain manufacturing processes are always going to be noisy, unless fundamentals of manufacturing change. And they might; it's happened before. During the Industrial Revolution, manufacturers were doing just fine using steam power. It didn't need replacing, in their minds, and nobody really saw how it might be improved on. Then Henry Ford came along and introduced mass production, the most fundamental shift in manufacturing's history. Most every mainstream product in our lives—airplanes, magazines, our chair, our desk—is available because of mass production. And mass production is an innovation that begets innovations. It is the most disruptive, world-changing shift in human history. And mass production is loud.

Long term, the only way to make stamping quiet is to replace it with something that achieves the same end but makes less noise. The question becomes one of impact. Will the loudness always be front and center? Probably not, and history backs that assertion.

Maybe tomorrow's factory will be really quiet. It won't happen overnight. And whatever comes next is likely to incorporate the best of mass production, just as each previous shift incorporated the best of its predecessor. One radically different manufacturing process, additive manufacturing, might change the noise equation completely. In additive manufacturing, layers are added to a part under computer control (no operator needed).

But that’s an option in the distant future. Digital manufacturing, the process of virtualizing activities that had been physical, is likely to be the "next" thing after conventional mass production. Still, digital manufacturing is in its embryonic stage, particularly among the small enterprises that make up the backbone of the manufacturing economy.

The factory of the near future is likely to look similar to the factory of today. Advanced automation will continue, offering opportunities to put humans farther and farther from the noisy equipment.

Editor’s note: The Barnes paper below emphasizes the importance of moving people from manufacturing areas, especially if they are highly skilled or their work is not directly related to manufacturing.

6.4 Past Experience With Placing Sales and Engineering Personnel on the Factory Floor

James D. Barnes, Principal, Acentech Incorporated

James Barnes described a consulting experience with a manufacturing company that wanted to house both executive and management, engineering and marketing on the factory floor. The case illustrates that noise issues can arise when manufacturing and other administrative functions share adjacent space. It provides a cautionary tale for the factory of the future.

With an eye toward the future and an increasingly competitive marketplace, the company was trying to adopt better practices. They recognized the need for a feedback loop across the entire organization. Rather than having management off to the side and engineering on another side and marketing off on their own, they chose to put all in the factory itself. To encourage teamwork, they organized their personnel along different product lines.

This ideal of enabling engineers and marketing and quality control people to offer ideas as they spring to mind during a walk past the production line came with concerns about safety and noise. So they measured sound levels. The company manufactured electrical components, which usually are 5 dB to 10 dB lower than really heavy manufacturing due to differences in processes. The sound levels were about 85 dB(A) to 90 dB(A) at the production stations and about 80 dB(A) to 85 dB(A) at supervisor and quality control desks. Those levels are markedly higher than the NC-40 to NC-50[2] goal for an HVAC system installed in an office space.

Barnes typically suggests the following maximum in-plant noise goals to address the need for worker speech communication and concern for worker exposure to noise within plant areas: Control room – 56 dB(A) (NC-50); Offices – 50 dB(A) (NC-43); Workshop – 66 dB(A) (NC-60); and depending on the type of plant, 75 to 85 dB(A) in the general floor areas and up to 85 to 95 dB(A) in limited access areas.

The company realized that its engineers and sales force would not be able to get their work done in that noisy environment. So they went back to the drawing board, asking: How can we design a factory for the future that allows close collaboration among all the different players, allowing them to talk and not be segregated, but still have a sound environment that is conducive to work.

One solution to consider is prefabricated rooms on the factory floor that offer windows and a nice environment, but also allow people to interact as well.

[2] Noise Criteria Curves. See Noise and Vibration Control Engineering, 2nd Edition, 2006, John Wiley &Sons, Hoboken, New Jersey. See page 869.

APPENDIX A

Calculation of sound levels in working areas as a planning tool for noise reduction

Wolfgang Probst, Managing Director, DataKustik GmbH, Germany

Foreword

The prediction of noise levels at industrial plants with machinery and other noise relevant facilities can be a valuable tool to ensure the lowest possible noise levels achievable with current technology and within a given budget. A prerequisite is the application of methods detailed enough to include the most important properties and parameters of the plant and the environment that can be adjusted to reduce the noise.

When industrial noise threatens close-by residential areas, noise prediction methods are commonly employed. In developed countries, gas turbine power plants, wind turbines or other noise relevant industrial facilities within critical distance to dwelling zones are generally not planned and installed before a prediction calculation has shown that maximal acceptable sound levels will not be exceeded. If this is not the case, additional measures can be taken into account and the process may be repeated.

Predicting occupational noise, or noise levels at workstations, is, by far, more difficult than predicting noise levels in residential areas outside for several reasons:

- the distance between the workstation and the machine is small relative to the extension of the source
- machines and other equipment are often very complex noise sources
- work stations and radiating equipment are, in most cases, inside rooms, and full 3D-calculations of many reflected sound contributions must be taken into account.

Nevertheless an effective software strategy adapted to the problems of occupational noise is now available and is presented in this appendix. The figures and the results obtained are based on the software program CadnaR [1].

The General Strategy to Include the Noise Aspect in Planning Activities

Planning of manufacturing facilities with respect to noise can only be effective if the different contributions to the noise level at a workstation are treated separately.

The Sources

The output of sound energy of noise sources, such as machines or other equipment, is sufficiently described by one number – the sound power level L_{WA} (see the ISO 3740 – series [2]).

This quantity is a property of the source and independent from the environment in which the source is located. The sound power level describes the sound radiated in all directions.

If a workstation, or an operator position, is connected with a machine, the emission sound pressure level L_{pA} (see the ISO 11200 – series [3]) gives additional helpful information to characterize the source. The emission sound pressure is the sound level the machine would produce in a free field, if operated with free space and no other noise sources around it.

It is obvious that the underlying operating conditions must be defined and documented.

These two quantities, L_{WA} and L_{pA}, both A-weighted levels with the unit dB(A), should be included for each machine and device for which noise emission is relevant. The values should be included in specifications and noise declarations (see the ISO 4871 [4]) by the suppliers, and finally in purchase contracts. In cases of assumed violation of given guarantees, the verification can be performed with measurements according to the above-mentioned standards.

The list with these two quantities (L_{WA} and L_{pA}) serves as an input list for the computerized simulation of the plant to calculate the noise levels at the work places with the complete plant in operation.

The Room

The acoustical specifications for the room also must be defined. The room's acoustical specifications are independent of the noise emission of the plant and only define the acoustical properties of the room. Suitable specifications are the level decrease per doubling of distance DL2 and level excess DLf (defined in ISO 14257 [5]).

The prediction methods described in this appendix allow the user to check in advance that the target values for DL2 and DLf will not be exceeded with the given room geometry, or if sound absorptive ceilings or other installations are necessary to meet the specification.

The supposed sound absorption coefficients of the absorbing surfaces applied as input parameters in the simulation calculation must be included as guaranteed values in the contract of purchase of the products.

In cases of assumed violation of given guarantees, verification can be performed by measuring the spatial sound decay curve according to ISO 14257. If the predicted values of DL2 and DLf are exceeded, an area of 10 m^2 of the installed absorptive surfaces can be removed and placed in a reverberation chamber to determine the absorption coefficient according to ISO 354 [6].

Prediction of Noise Levels at Workstations

If the plant is in typical operation, the quantities mentioned above, which quantify the sound emission of machinery and other technical devices as well as the sound absorptive properties of the room surfaces, are the input parameters for a simulation to calculate the sound pressure levels at work places. Using new and now-available software tools, important phenomena such as sound screening, absorption, scattering and transmission through light-weight structures can be quantified. Noise abatement measures can thus be included to obtain the economically most advantageous solution with all the noise specifications met. This process must be performed by acoustically experienced engineers who understand the software application and product solutions.

The Software Strategy to Predict Noise Levels

There are two fundamentally different approaches to calculate sound propagation inside rooms with many reflections influencing the sound pressure levels at receiver positions. The first method is based on sound rays – all the possible ray paths from source to receiver must be constructed to get the final result. If a ray between source and receiver is reflected n-times, this is a reflection of n^{th} order.

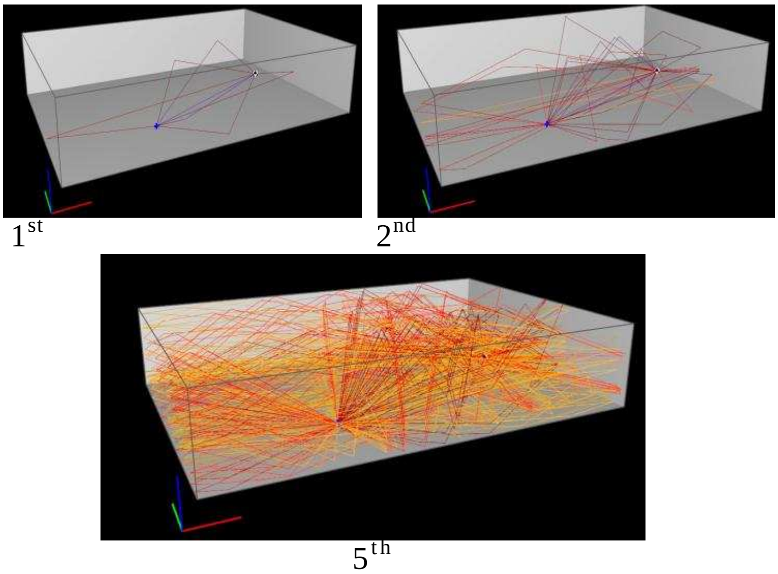


Figure A-1. *Sound rays constructed with the ray-based method.*

The upper left image in Figure A-1 shows direct ray and 6 rays of 1st order, the upper right image shows all rays of 1st and 2nd order. The lower image shows all reflected rays up to the 5th order. The advantage of the ray-based method is that sound attenuation by screening can easily be taken into account.

This exponential increase in calculations necessary with higher reflection orders—and the more reverberant a room, the more reflection orders have to be taken into account—is by far less dramatic with the particle method shown in Figure A-2.

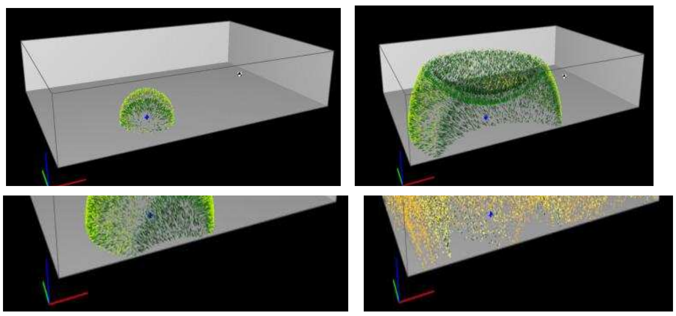


Figure A-2. *Sound propagation simulated with the particle method.*

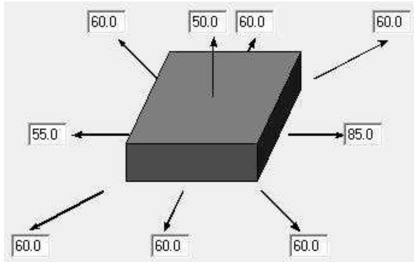
Thousands or even millions of statistically distributed “sound particles” are radiated in all directions from the sound source and follow a straight propagation line between the reflections at surfaces from the room or from other objects.

The most important step in the process of noise prediction for planned industrial plants with machinery is the modeling. The layout with all geometrical and acoustical parameters relevant for the resulting noise levels must be transferred into a virtual model.

Small machines and devices such as the press shown in Figures A-3a and A-3b are simulated by a simple point source and the location in the room is defined by the coordinates x, y and z, and the noise emission by the standardized values L_{WA} and L_{pA} mentioned above.

The filling machine shown in Figure A-4 is enclosed in a light casing for security reasons. Sound is radiated from a larger surface and produces a sound field that cannot be simulated by a small point source.

Figure A-3a. *Press radiating sound.*



FigureA-3b. *Simulation by a simple point source with information about directivity. This is a simple definition of directivity.*

Figure A-4. *Filling machine in a bottling plant.*

Figure A-5 shows three examples for the simulation of larger box-type machines. The box can have any size and even be elevated to consider sound particles propagating underneath.

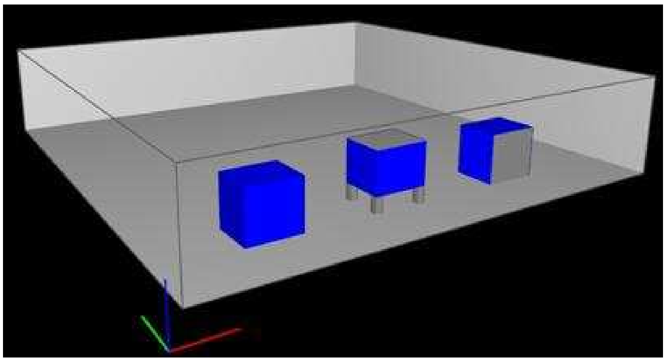


Figure A-5. *Simulation of three box-type machines with different surfaces radiating sound.*

With the combination of point sources, line sources and such box-type structures, machines of any complexity can be modeled. Figure A-6a shows a large bottle-washing machine in a bottling plant and Figure A-6b the corresponding 3D-model.

The easy assembly of such machines from basic elements is an important property of simulation software used frequently for noise prediction. The emission values L_{WA} and L_{pA} are applied as information for the sound emission, and the emission of all the partial sources must be adapted automatically to these input data.

The paths of the sound particles emitted from the noise-relevant machine parts as shown in Figure 7 are calculated taking into account that the massive body of the machine is acoustically opaque.

Figure A-6a. *Large washing machine in a Bottling plant.*

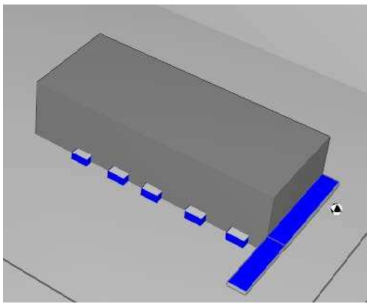


Figure A-6b. *Computer model of the washing machine.*

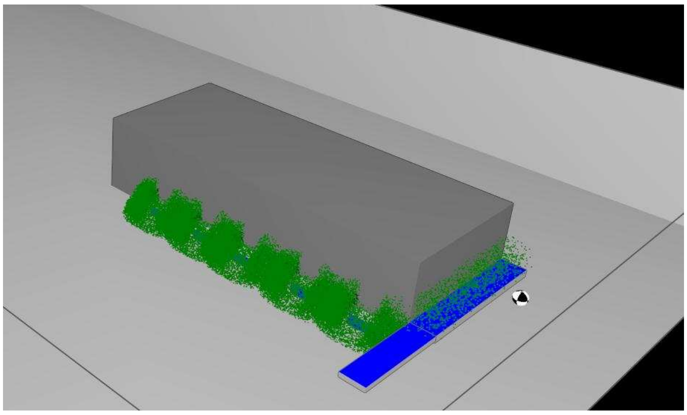


Figure A-7. *Sound particles are emitted from the noise relevant parts of this machine.*

The distribution of sound pressure levels in a room are calculated by counting the number of particles that cross a little control volume around the receiver. Figure A-8 shows the room segmented into such box-type control volumes or “voxels.”

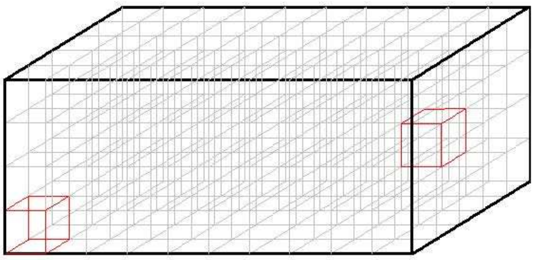


Figure A-8. *Subdivision of the room into “voxels” to count the crossing particles.*

Figure A-9a shows the machine located in the middle of a room; Figure A-9b shows the distribution of calculated sound pressure levels with walls and ceiling completely absorptive, thus simulating free field propagation. The yellow color at the back side of the massive machine indicates the low noise levels due to the screening effect of the massive machine body. In Figure A-9c, walls and ceiling are assumed to be reflective and calculations up to high reflection orders have been performed. The level distribution is smoother by far, which is caused by including the sound from the additional sound-immission from high order reflections inside this room.

The main advantage of the method presented is the possibility to integrate locally effective noise reduction measures, and to check their effect on receiver levels.

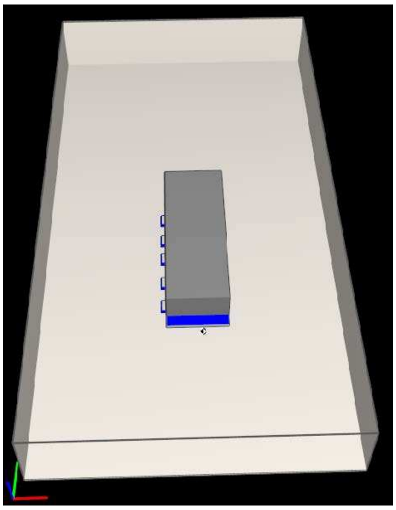


Figure A-9a. *Machine inside room.*

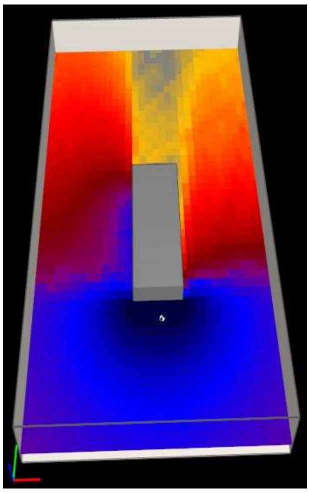


Figure A-9b. *Level distribution with sound absorptive walls and ceiling.*

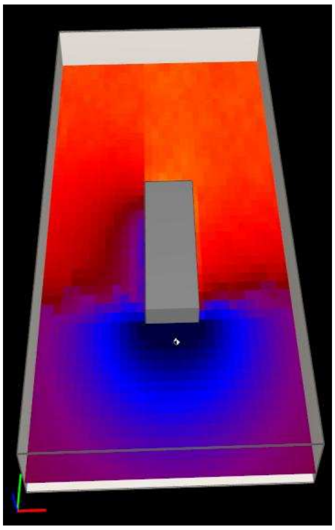


Figure A-9c. *Level distribution with reflecting walls and ceiling.*

As an example, Figures A-10a and A-10b show the protection of a workstation by an optically transparent screen serving as a noise barrier to lower the sound exposure at this position. It is even possible to integrate an absorptive baffle system above the barrier to reduce the sound reflected by the ceiling. Figure A-11 shows the penetration of sound particles through such an open structure with baffles.

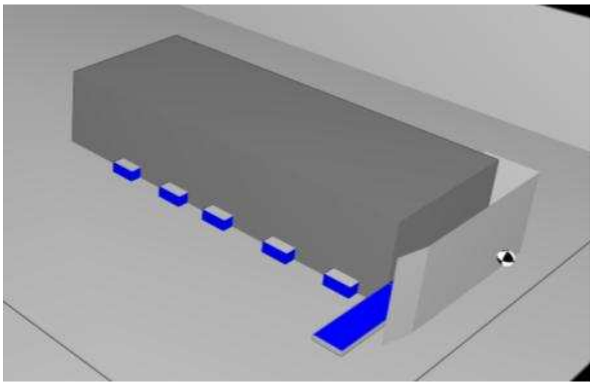


Figure A-10a. *Transparent screen between workplace and machine.*

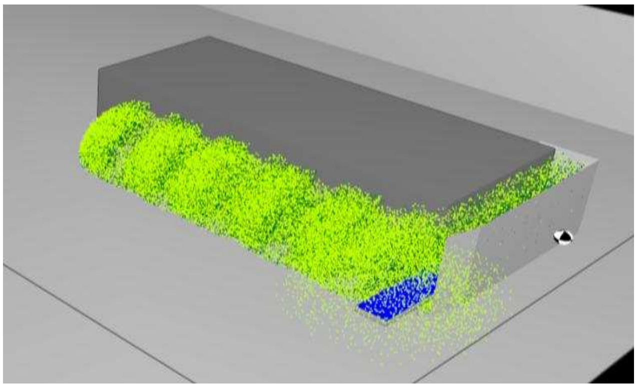


Figure A-10b. *Sound particles reflected by the screen.*

The calculation of the level at the work place results in 84 dB(A) for a free field (Figure 9b), 89 dB(A) in the room (Figure 9c), 87 dB(A) with protecting screen (Figures A-10a and b) and 85 dB(A) with a sound-absorptive ceiling (Figure A-11).

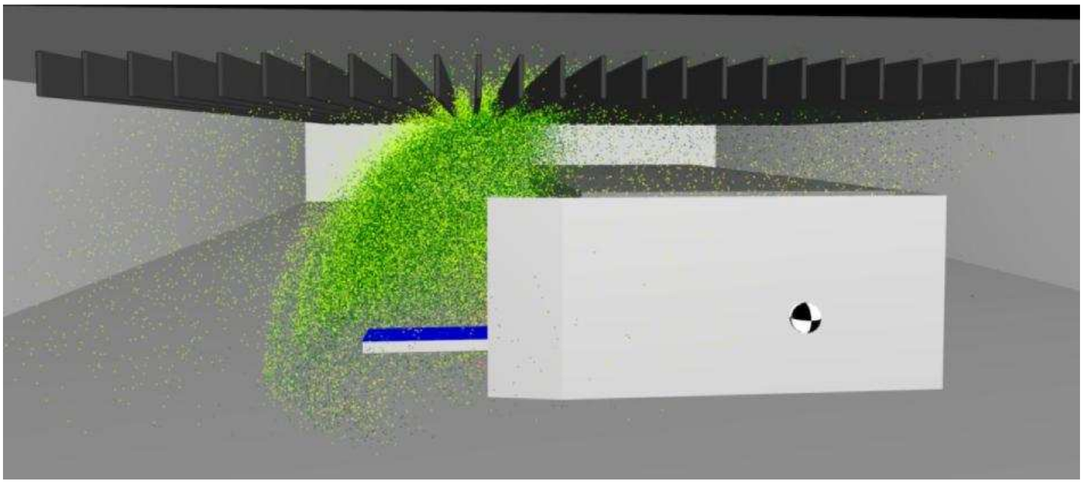


Figure A-11. *Absorbing baffle structure above the machine (each baffle is modeled as a separate sound-absorptive object)*

The advantages of this software strategy become obvious if complete plants are modeled, as shown in Figure A-12. The data structure of each machine, once created and saved in a library, can be treated as one single element, integrated in the plant layout, transformed, duplicated or otherwise modified and adapted to the emission values L_{WA} and L_{pA} declared by the manufacturer or otherwise determined. This “Object Tree” is a data organization in which all the elements a machine consists of are saved in one folder with the machines name and, after calculation, the level caused by each machine separately. The total level is also listed for each workstation. This structure facilitates the otherwise extremely time consuming development of necessary noise reduction measures to reach the defined target values, for example 85 dB(A) at workstations. Figures A-13, A-14 and A-15 show the plant in 3D-representation without treatment, with an absorptive plane ceiling, and with a baffle construction.

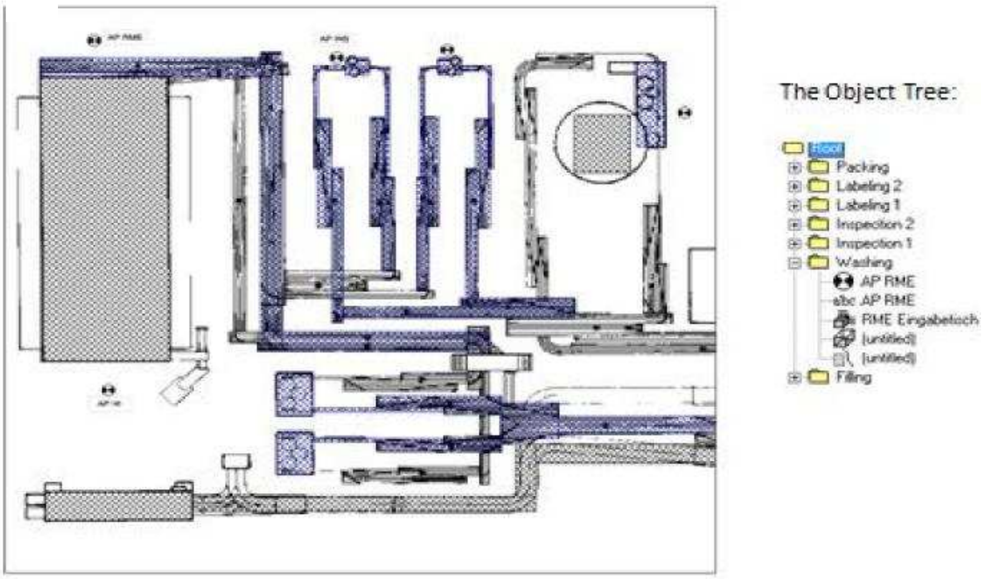


Figure A-12. An object tree of a full room.

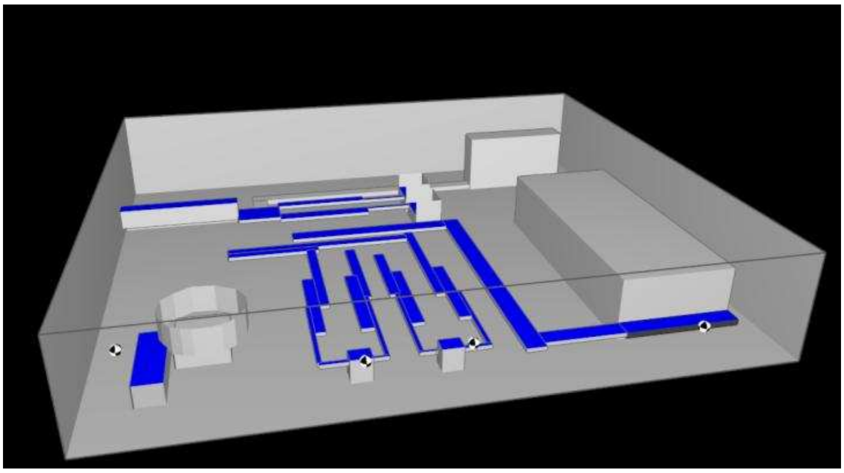


Figure A-13. *3-D model of the complete plant with no treatment of room surfaces.*

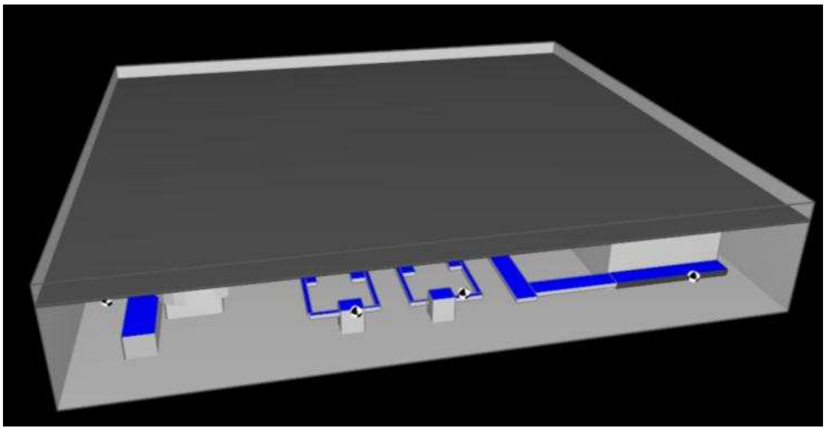


Figure A-14. *3-D model of the bottling plant with absorbing suspended ceiling.*

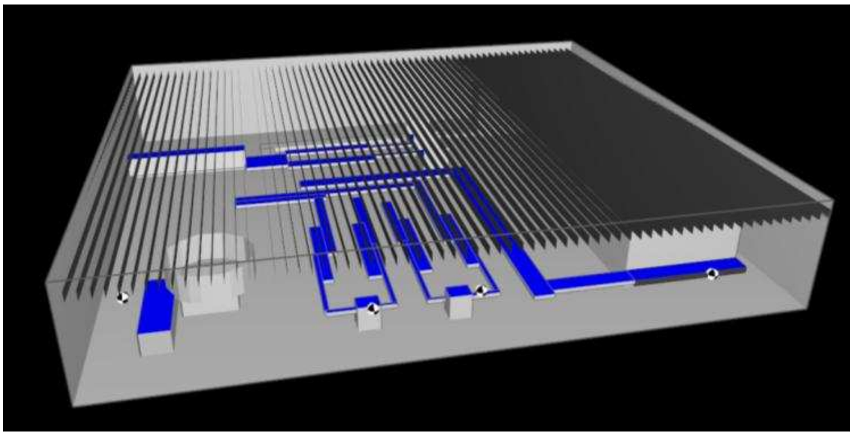


Figure A-15. *3-D modeling of the bottling plant with baffle system.*

Future Prospects

These few examples from the bottling industry demonstrate the principles of computer modeling of a work place. The creation of virtual models of production plants and other facilities with workstations where noise exposure may be an issue will become a more and more increasingly important part of the planning process. The plant shown in Figures A-13 through A-15 is a simplified 3D-presentation of a CAD drawing. The machines, conveyors, pipes, and other technical facilities are broken down and simplified to contain only those elements that are relevant for sound emission and propagation. Such a model is an excellent basis for all discussions of the pros and cons of alternative strategies to reach low noise exposures, and makes it possible to minimize the expenses necessary to reach defined not-to-be-exceeded target noise levels.

It is, of course, helpful if machinery suppliers provide a file with an acoustical 3D model of the machine in the configuration as it is offered. This would reduce the work to negotiate over noise issues because the data file contains required information. It is, in a certain sense, customer-oriented support and replaces any declaration and other formal procedures.

This software-based technique is not only a future-oriented approach to create work places with the probability of hearing damage reduced, but also allows other aspects of sound impact to be controlled. An example is the planning of large open plan offices, where the layout is to be optimized to reduce the disturbance by other people speaking or where good speech intelligibility between the members of a working group is to be ensured.

An example of an acoustical 3D-model of an office is shown in Figure A-16. The model is simplified with respect to architectural aspects, but contains all information on the acoustical properties of furniture, suspended ceiling, and other fittings.

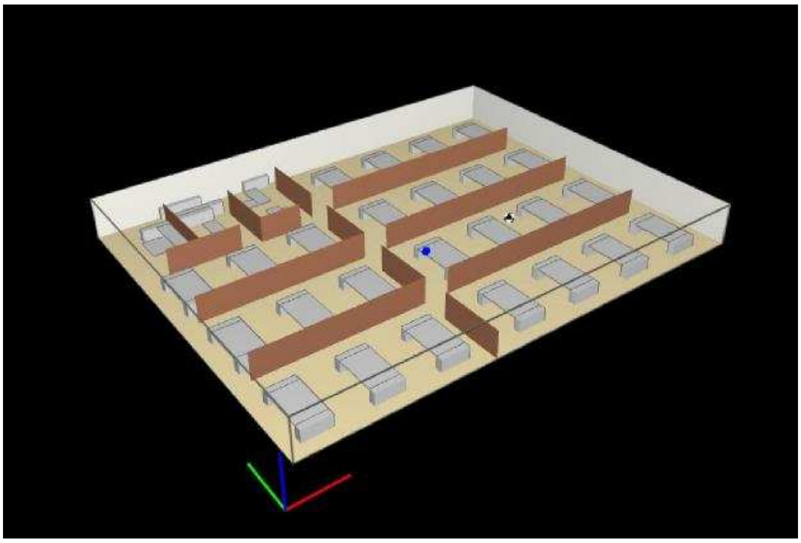


Figure A-16. *Acoustically oriented 3D-model of an extended office area.*

The partial screens subdividing the area into different sub-areas should be arranged in a way that members of each working group can easily communicate but will not be disturbed by speech from other groups.

This can be achieved by approximate determination of the STI (Speech Transmission Index) or other room acoustical parameters and identification of the area in the work place where a person speaking is well understood. This is the area inside the “distraction distance.” A zone outside of this area may be called the “privacy distance” where there is a high probability that understanding speech is not possible.

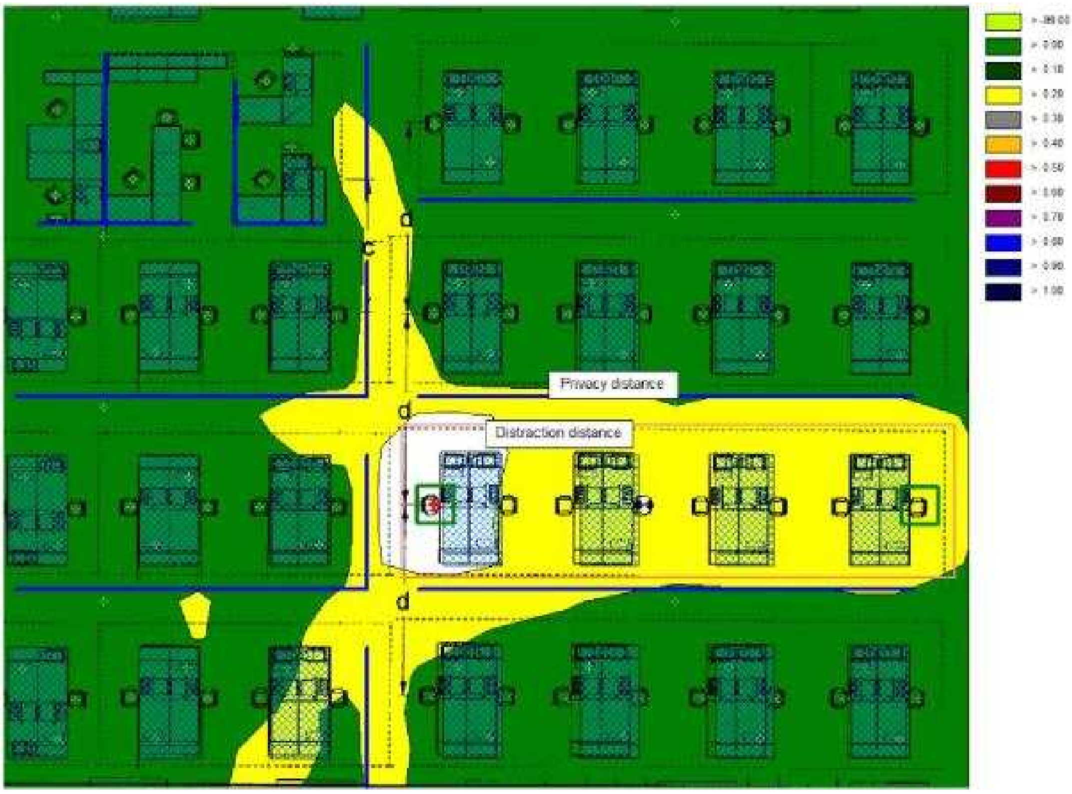


Figure A-17. Distraction distance and distance around a work place based on the calculated STI.

These methods are to be improved step by step and incorporated into the planning of office working areas.

Annex - Validation of the Calculation Method

Many measurements have been performed in the last decades to obtain reliable data that may be used to check the accuracy of calculation methods.

One such set of measurements was obtained by placing a transportable screen in different environments inside empty and fitted industry halls, and to measure the sound levels at different distances behind the screen. A dodecahedron loudspeaker produced well-defined sound emission in each frequency band at the opposite side of the screen. Figure A-18 shows such an experimental setup in a retention basin with many sound scattering columns, which influenced the sound propagation.

Figure A-18. *Measuring the screening effect with a transportable screen in a retention basin.*

In another case, levels in 122 industrial halls produced by a well-defined source at receiver positions distributed along a straight line were measured.

Figure A-19 shows the measuring setup where the octave band spectra measured along a straight line with the dodecahedron radiating with a well-known octave band sound power level. The reverberation time was also measured. The data set in Table A-1 contains the geometric information on the room and measuring positions, the sound power level of the source, and the absorption coefficients of walls, ceiling and floor—applying a classification scheme developed in advance. The data set also contains the measured reverberation times and octave band spectra at the receiver positions and, last but not least, an estimate of the density of scattering objects.

A model was created from each of these data sets—in an automated process—as it is shown in Figure A-20.

Figure A-19. *Measuring setup with a dodecahedron loudspeaker in a bottling plant.*

Table A-1. A sample set of data obtained for each of 122 halls.

1	3					ObjektNr / ZustandsNr
Industriebetrieb XXYZ						Name
mit RA-Massnahmen / mit Maschinen						Zustand
30	20	4.5				Länge / Breite / Höhe
0.045						Streukörperdichte
0.06	0.075	0.075	0.075	0.085	0.105	Streukörperabsorption
0.06	0.073	0.074	0.076	0.08	0.1	Absorptionsgrad Wand 1
0.06	0.073	0.074	0.076	0.08	0.1	Absorptionsgrad Wand 2
0.06	0.073	0.074	0.076	0.08	0.1	Absorptionsgrad Wand 3
0.06	0.073	0.074	0.076	0.08	0.1	Absorptionsgrad Wand 4
0.25	0.5	0.65	0.8	0.85	0.85	Absorptionsgrad Decke
0.06	0.073	0.074	0.076	0.08	0.1	Absorptionsgrad Boden
1	0.88	0.72	0.65	0.64	0.58	Nachhallzeiten
107.9	112.8	108.6	104.4	104.6	97.7	Schalleistungspegel Quelle
1.5	9	1.5	30	9	1.5	Pfadanfang X/Y/Z, Pfadende X/Y/Z
1 / 2 / 3 / 4 / 5 / 6 / 7 / 8 / 9 / 10 / 12 / 14 / 16 / 18 / 20 / 22 /						Abstände Quelle - IP
100.0	101.7	97.9	95.5	94.8	89.7	IP 1
94.1	98.9	94.5	91.5	92.3	85.0	IP 2
92.3	94.3	89.9	87.2	86.7	80.8	IP 3
91.3	92.1	88.9	87.4	85.5	78.9	IP 4
91.1	91.3	88.2	85.5	85.7	78.9	IP 5
88.8	90.3	87.0	84.0	86.7	78.2	IP 6
87.0	89.9	85.7	83.1	85.5	78.1	IP 7
88.5	89.5	85.2	82.7	84.3	77.9	IP 8
89.4	89.0	85.7	81.4	84.4	76.7	IP 9
91.8	89.3	83.1	80.8	82.7	75.1	IP 10
86.9	89.2	82.6	78.8	81.4	73.9	IP 11
83.7	86.2	80.6	75.5	79.0	72.3	IP 12
87.2	86.7	79.7	75.0	77.6	70.6	IP 13
85.4	86.6	78.4	73.6	76.8	69.4	IP 14
85.0	84.8	78.0	73.7	76.3	68.6	IP 15
84.6	85.2	76.5	73.8	76.2	68.9	IP 16

The arrangement of scattering objects was determined from the scattering density mentioned above presuming a size of the objects typical for machinery. The octave band levels were calculated at each receiver position and subtracted from the measured levels taken from the data set.

Typical results for one industrial hall are shown in Figures A-21, A-22 and A-23. The measured and calculated levels are shown as a function of the distance from the source.

Figure A-21 is based on the room complete empty and not fitted, Figure A-22 with an absorbing ceiling installed but otherwise empty, and Figure A-23 the same hall with a sound-absorptive ceiling and with the plant and machinery installed. It is obvious that the particle model applied to calculate sound propagation is well suited to illustrate the different acoustical properties of the room.

Finally, a statistical evaluation of level differences for all distances is shown in Figure A-24. This final result shows excellent agreement of calculated and measured levels – the mean value (red) is nearly zero and 50 percent of all differences are smaller than ± 1 dB. Therefore the particle-method applied is well suited to calculate sound propagation in a closed room with various types of equipment installed.

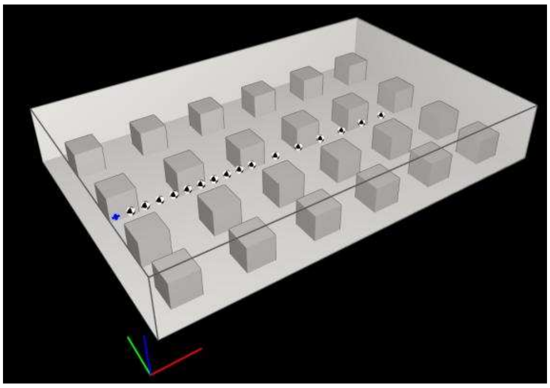


Figure A-20. *The model created automatically from the data shown in Figure 19.*

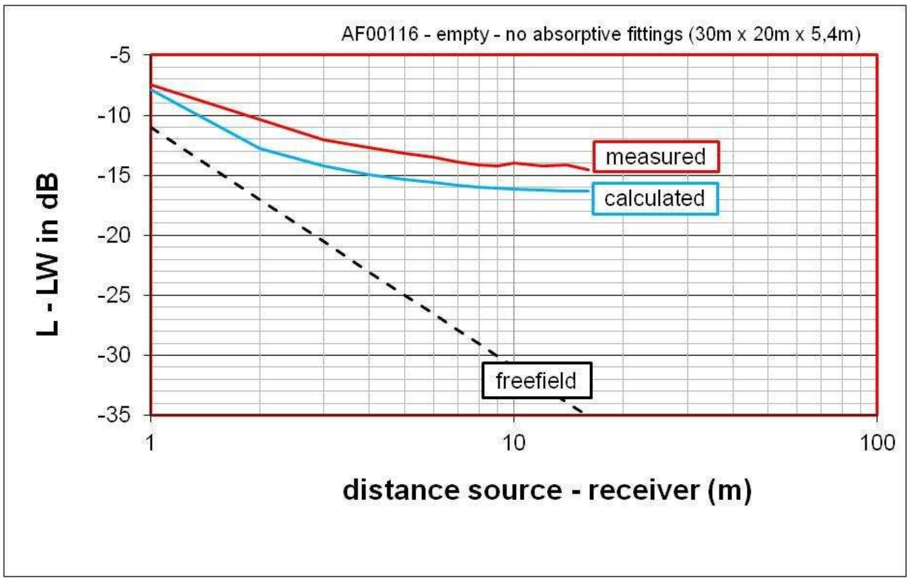


Figure A-21. *Comparison of calculated and measured levels with the room empty.*

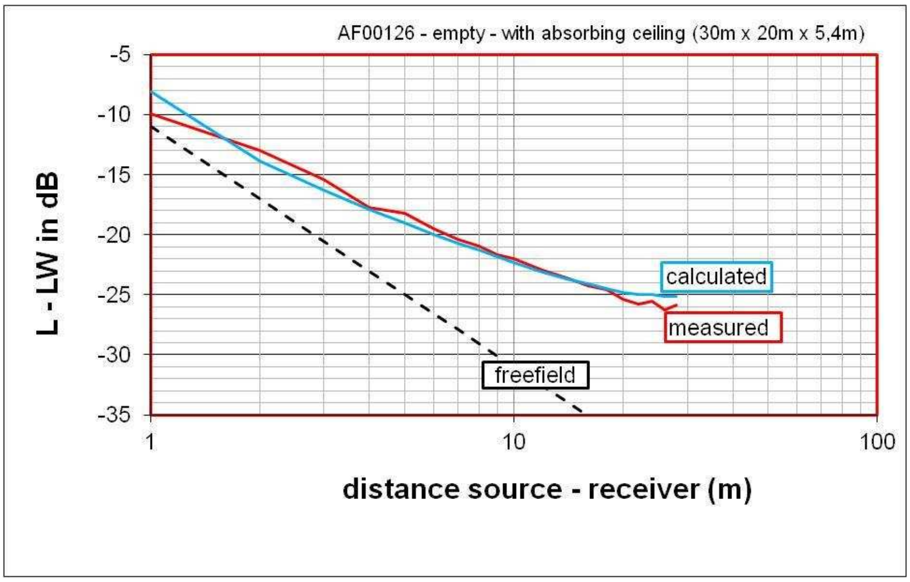


Figure A-22. *Comparison of calculated and measured levels with the room empty but with a sound-absorptive ceiling.*

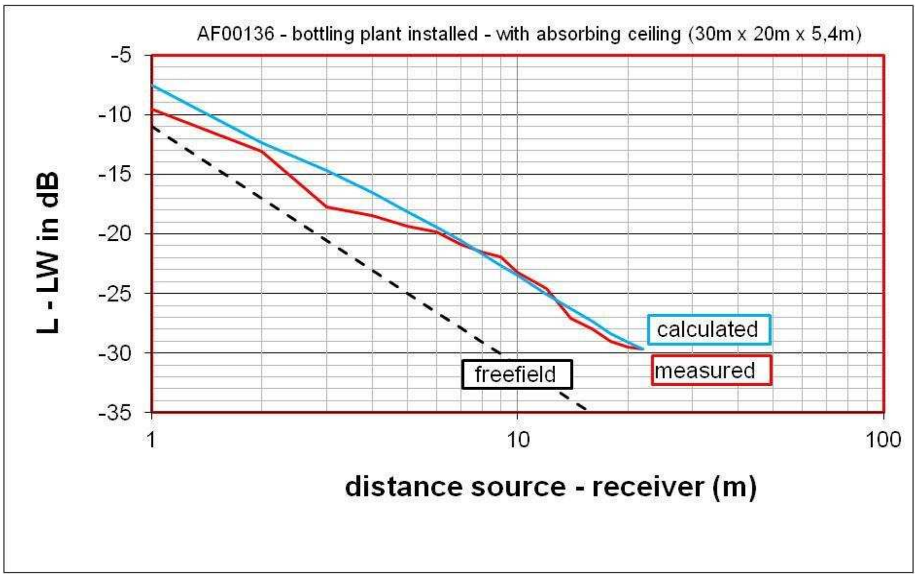


Figure A-23. *Comparison of calculated and measured levels with a sound absorptive ceiling and with machinery installed.*

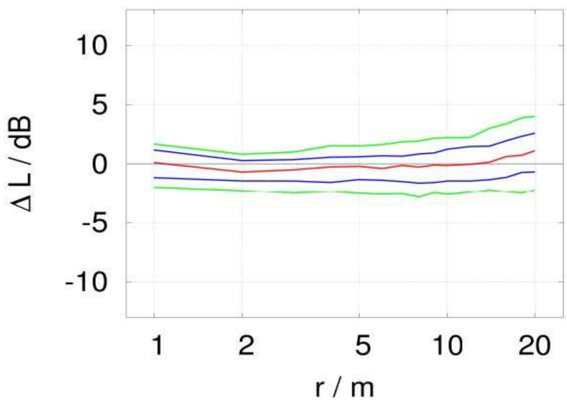


Figure A-24. *Statistics of level differences calculated – measured (Red = mean, blue = 50%, green = 80%).*

References

1. CadnaR – Prediction of Noise Levels inside Rooms
http://www.datakustik.com/en/products/cadnar/
2. ISO 3744: Acoustics – Determination of sound power levels and sound energy levels of noise sources using sound pressure – Engineering methods for an essentially free field over a reflecting plane.
www.iso.org/iso/iso_catalogue/catalogue_tc/catalogue_detail.htm?csnumber=52055
3. ISO 11204: Acoustics – Noise emitted by machinery and equipment – Measurement of emission sound pressure levels at a work station and other specified positions applying accurate environmental corrections. www.iso.org/iso/catalogue_detail.htm?csnumber=54906
4. ISO 4871: Acoustics – Declaration and verification of noise emission values of machinery and equipment. www.iso.org/iso/catalogue_detail.htm?csnumber=10855
5. ISO 14257: Acoustics – Measurement and parametric description of spatial sound distribution curves in workrooms for evaluation of their acoustical performance.
www.iso.org/obp/ui/#iso:std:iso:14257:ed-1:v1:e
6. ISO 354: Acoustics – Measurement of sound absorption in a reverberation room.
www.iso.org/iso/catalogue_detail.htm?csnumber=34545

APPENDIX B

Final Program

Reducing Employee Noise Exposure in Manufacturing—Best Practices, Innovative Techniques, and the Workplace of the Future

A Follow-up Workshop to the NAE *Technology for a Quieter America* Report (2010)

Organized by the U.S. National Institute for Occupational Safety and Health, the TQA Follow-up team, and the INCE Foundation
Hosted by the National Academy of Engineering

February 19-20, 2014

The National Academies Keck Center, Room 101
500 5th Street, NW
Washington, DC 20001

Wednesday, February 19

8.30 **Welcoming Remarks**
Proctor Reid
Director, Program Office
National Academy of Engineering

Introduction of Attendees

Opening Remarks
W. Gregory Lotz and George C. Maling, Jr.
Workshop Co-Chairs

Session 1. Noise Control Programs in Manufacturing Industries

8.50 **Introduction to the NIOSH Safe in Sound Award**
W. Gregory Lotz
Division Director
National Institute for Occupational Safety and Health

9.00 **Towards No Noise-Induced Hearing Loss: One Company's Journey**
John Downey
Colgate-Palmolive

9.30 **Getting the Noise Out - A Multipronged Approach to Managing Noise Exposures in Manufacturing**
John Mulhausen
Director, Corporate Safety and Industrial Hygiene
3M Company

10.00 ---------------- *BREAK*

10.15 **Benefits of Noise Reduction in a Manufacturing Environment**
Mike Roberto and Tu Dam
Environmental Health and Safety Supervisor and Human Resources Manager
General Dynamics **-** *OTS*
Red Lion Operations

10.45 **Reducing Employee Noise Exposures: A Recent Manufacturing Plant Example**
Eric W. Wood
Director Emeritus, Noise Control Division
Acentech Incorporated

11.15 **Noise Reduction Process**
James K. Thompson
Chief, Hearing Loss Prevention Branch
National Institute for Occupational Safety and Health

11.45 **A History of Noise Control in the Textiles, Tobacco, and Woodworking Industries**
Noral D. Stewart
Stewart Acoustical Consultants

12.15 --------------- *LUNCH*

Session 2. Engineering for Noise Control in Manufacturing

1.15 **The Calculation of Sound Levels in Working Areas as a Planning Tool for Noise Reduction**
Wolfgang Probst
Head ofResearch and Development Managing Director
DataKustik GmbH

1.45 **Progress and Failures in US Manufacturing Noise Reduction**
Robert Bruce
Principal
CSTI Acoustics

2.15 **Engineering Controls for Reduction of Industrial Noise Exposures**
Robert R. Anderson
Anderson Consulting Associates

2.45 **Considerations for an Effective Hearing Conservation Program.**
Dan Westrum
Industrial Hygienist
3M Stationary Products Division

3.15 **Evaluation of Noise Exposure at a Metal Conduit Manufacturer**
Scott Brueck
Industrial Hygienist
Health Effects and Technical Assistance Branch
National Institute for Occupational Safety and Health

3.45 ----------------- *BREAK*

4.00 **Examples of Noise Control Technology Available for Manufacturing Equipment**
James D. Barnes
Principal
Acentech Incorporated

4.15 **Compressors and Pneumatic Tools**
Michael Lucas
Principal Engineer
Ingersoll Rand Industrial Technologies

4.45 **Advanced Acoustics for Quiet Power Generator Sets**
Shashikant More
Technical Specialist, Mechanical Engineering
Cummins, Inc.

5.15 **Discussion**

5.30 **Close**

Thursday, February 20

Session 3. The Manufacturing Environment of the Future

8.30 **The NAE Program Related to Future Manufacturing**
Kate Whitefoot
Senior program officer for manufacturing, design, and
innovation National Academy ofEngineering

8.45 **NIST MEP Next Generation Strategy and the Future of US Manufacturing**
Daniel Lilley
Regional Manager for Strategic Transition
NIST/MEP

9.00 **You Could Eat Off this Floor (but...why?): Tomorrow's Industrial Spaces**
Rebecca R. Taylor
Senior Vice President
National Center for Manufacturing Sciences

9.30 **Past Experience with Placing Sales and Engineering Personnel on the Factory Floor**
James D. Barnes
Principal
Acentech Incorporated

9.45 ------------------ *BREAK*

10.00 **A Brief Introduction to Buy Quiet Programs**
George C. Maling, Jr.
Member, NAE
Workshop Co-Chair

10.30 **American National Standards for Noise Emission Measurements**
William J. Murphy
Leader, Hearing Loss Prevention Team
Chair, ANSI/ASA S12 Subcommittee on Noise
National Institute for Occupational Safety and Health

11.00 **Discussion**

12.00 ---------------- *LUNCH*

Session 4. Noise Reduction by Programs and Process Change

1.00 **The FRITA Project: Reducing Noise and Improving Safety**
Rebecca R. Taylor
Senior Vice President
National Center for Manufacturing Sciences

1.20 **Change from Reciprocating Equipment to Rotating Equipment in Candy Manufacture: Lower Noise and Other Benefits** *James D. Barnes*
Principal
Acentech Incorporated

1.40 **Noise Reduction and Productivity Improvement for a Paper Shredding Operation (short case history)**
Noral D. Stewart
Stewart Acoustical Consultants

2.00 ----------------- *BREAK*

Session 5. Advanced Techniques for Noise Reduction

2.15 **Aeroacoustic Modeling and Simulation of Compressors and Pneumatic Tools**
Michael Lucas
Principal Engineer
Ingersoll Rand Industrial Technologies

2.45 **Advanced methods for noise source localization on machines**
Earl G. Williams
Senior Scientist for Structural Acoustics & Sound Field Reconstruction and Associate Editor, Journal of the Acoustical Society ofAmerica
Naval Research Laboratory

3.15 **The Physics of Low Noise Design**
David Herrin
University of Kentucky

3.45 **Discussion**

5.30 **Close**

APPENDIX C

Workshop Attendance List
Final

Anderson, Robert R.
Anderson Consulting Associates
Lansing, MI

Barnes, James D.
Principal
Acentech Incorporated
Cambridge, MA

Bruce, Robert
Principal
CSTI Acoustics
Houston, TX

Brueck, Scott
Industrial Hygienist
DSHEFS
NIOSH
Cincinnati, OH

Dam, Tu
Human Resources Mgr.
General Dynamics - OTS
Red Lion Operations
West Lion, PA

Downey, John
Associate Manager, Global Industrial Hygiene
Colgate-Palmolive
Piscataway, NJ

Feith, Kenneth E.
U.S. EPA (retired)
N. Potomac, MD

Herrin, David
Department of Mechanical Engineering
University of Kentucky
Lexington, KY

Lang, William
Noise Control Foundation
Poughkeepsie, NY

Lilley, Daniel
Regional Manager for Strategic Transition
NIST/MEP
Gaithersburg, MD

Lotz, Gregory
Workshop Co-chair
Division Director
DART
NIOSH
Cincinnati, OH

Lucas, Michael
Principal Engineer
Air Solutions
Ingersoll Rand Industrial Technologies
Davidson, NC

Maling, Jr., George C.
Workshop Co-Chair
Member, NAE
Harpswell, ME

More, Shashikant
Technical Spec.
Mechanical Eng.
Cummins, Inc.
Findley, MN

Mulhausen, John
Director, Corporate Safety and Industrial Hygiene
3M Company
St. Paul, MN

Murphy, William J.
Hearing Loss Prevention Team Leader
DART
NIOSH
Cincinnati, OH

Probst, Wolfgang
Head of Research and Development
Managing Director
DataKustik GmbH
Greifenberg, Germany

Reid, Proctor
Director, Program Office
National Academy of Engineering

Roberto, Mike
Environ. Health & Safety Super.
General Dynamics - OTS
Red Lion Operations
West Lion, PA

Stewart, Noral D.
Stewart Acoustical Consultants
Raleigh, NC

Taylor, Rebecca R.
Sr. Vice President
NCMS
Washington, DC

Thompson, James K.
Hearing Loss Prevention Branch Chief
OMSHR
NIOSH
Pittsburgh, PA

Vanchieri, Cory
Rapporteur
Silver Spring, MD

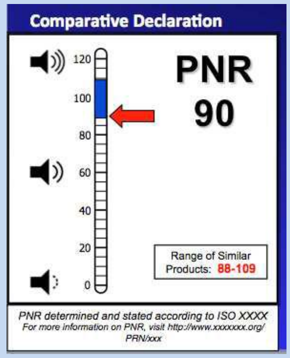
Westrum, Dan
Industrial Hygienist
3M Stationery Products Division
Hutchinson, MN

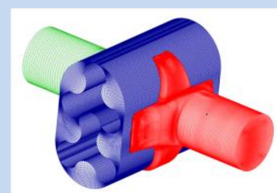
Whitefoot, Katie
Senior Program Officer for Manufacturing,
Design, and Innovation
National Academy of Enginering
Washington, DC

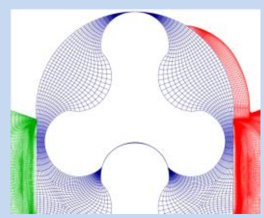
Williams, Earl G.
Senior Scientist for Structural Acoustics & Sound Field
Reconstruction
Naval Research Laboratory
Washington, DC

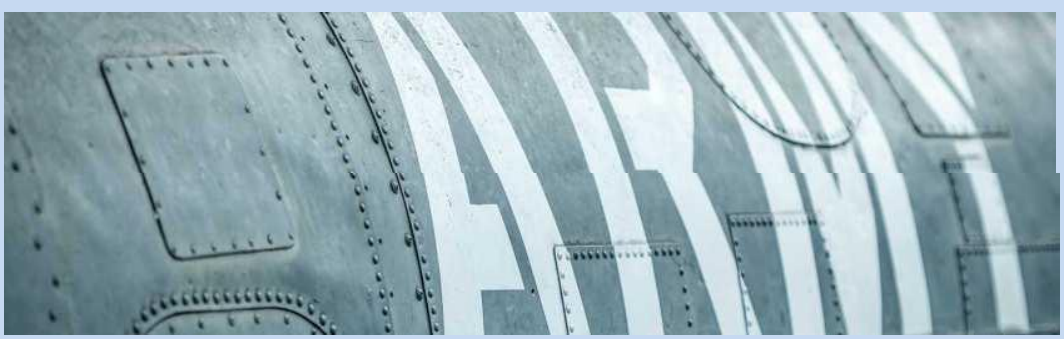
Williams, Jason
NAE Staff

Wood, Eric
Director Emeritus
Noise Control Division
Acentech Incorporated
Cambridge, MA









This report, *Reducing Employee Noise Exposure in Manufacturing*, describes hearing conservation programs in manufacturing industries, best practices for noise control in manufacturing industries, engineering for noise control in manufacturing, innovative techniques for engineering noise control, and the manufacturing workplace of the future.