NOISE/NEWS INTERNATIONAL

Volume 18, Number 2
2010 June

A quarterly news magazine with an Internet supplement published by I-INCE and INCE/USA

SPECIAL ISSUE FEATURE ARTICLE ON THE OTTAWA FORUM:
Worldwide Noise Sources

INTER-NOISE 2011
First Announcement

NOISE-CON 2011
First Announcement

NOISE-CON 2010 REPORT

MEMBER SOCIETY PROFILE
The Swedish Acoustical Society

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Noise Control Engineering Journal

— An International Publication —

NOISE/NEWS INTERNATIONAL

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Grand Cube Osaka, venue for INTER-NOISE 2011 in Osaka, Japan. Photo courtesy of the Osaka Convention and Tourism Bureau

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NOISE/NEWS INTERNATIONAL

This PDF version of Noise/News International and its Internet supplement are published jointly by the International Institute of Noise Control Engineering (I-INCE) and the Institute of Noise Control Engineering of the USA (INCE/USA). This is the first volume that is being published in PDF format only. The PDF format means that the issues can be read by freely available software such as that published by Adobe and others. It reduces publication time, saves printing costs, and allows links to be inserted in the document for direct access to references and other material. Individuals can sign up for a free subscription to NNI by going to the web site http://www.noisenewsinternational.net

I-INCE

The International Institute of Noise Control Engineering (I-INCE) is a worldwide consortium of societies concerned with noise control and acoustics. I-INCE, chartered in Zürich, Switzerland, is the sponsor of the INTER-NOISE Series of International Congresses on Noise Control Engineering, and, with the Institute of Noise Control Engineering of the USA, publishes this quarterly magazine and its Internet supplement. I-INCE has an active program of technical initiatives, which are described in the Internet supplement to NNI. I-INCE currently has 46 Member Societies in 39 countries.

INCE/USA

The Institute of Noise Control Engineering of the USA (INCE/USA) is a non-profit professional organization incorporated in Washington, D.C., USA. The primary purpose of the Institute is to promote engineering solutions to environmental noise problems. INCE/USA publishes the technical journal, *Noise Control Engineering Journal*, and, with I-INCE publishes this quarterly magazine and its Internet supplement. INCE/USA sponsors the NOISE-CON series of national conferences on noise control engineering and the INTER-NOISE Congress when it is held in North America. INCE/USA Members are professionals in the field of noise control engineering, and many offer consulting services in noise control. Any persons interested in noise control may become an Associate of INCE/USA and receive both this magazine and *Noise Control Engineering Journal*.

NNI and its Internet Supplement

www.noisenewsinternational.net

The primary change in this PDF-only volume of *NNI* is the ability to have “hot links” to references, articles, abstracts, advertisers, and other sources of additional information. In some cases, the full URL will be given in the text. In other cases, a light blue highlight of the text will indicate the presence of a link. At the end of each feature or department, a light blue back to toc will take the reader back to the table of contents of the issue.

- The Internet supplement contains additional information that will be of interest to readers of *NNI*. This includes:
- The current issue of *NNI* available for free download
- *NNI* archives in PDF format beginning in 2003
- A searchable PDF of annual index pages
- A PDF of the current *NNI* conference calendar and a link to conference calendars for worldwide meetings
- Links to I-INCE technical activities and I-INCE Technical Reports

INCE/USA: The State of the Institute

Before I get into the State of the Institute, INCE/USA, I want to say how honored I am to serve as the new President of the Institute. Many years ago in my first term on the Board of Directors, I was very impressed to meet and work with several people whom I considered legends in noise control. I was very humbled by this experience, and now am amazed that I have the opportunity to lead the organization. I will do my best, and want to acknowledge the fact that I can accomplish nothing without support and hard work of the members of the Board of Directors and the Officers of the Institute. INCE/USA is fortunate to have a strong group of dedicated volunteers who work tirelessly for the Institute and its members. I am very proud to be a part of this team.

Let me get to the true subject of this note—the recent survey I conducted to assess the State of the Institute. We contacted 42 members and asked for their feedback on all aspects of INCE/USA and the programs it conducts. The respondents were very thorough, providing pages of comments and suggestions in many instances. The most important finding from this survey was the high value placed on INCE/USA membership. The praise for the Institute was outstanding with many citing it as the most valuable professional organization to which they belonged.

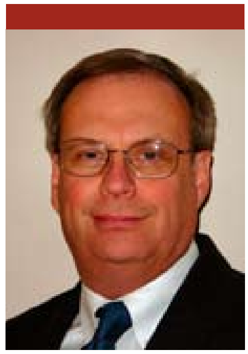
The planning and operation of NOISE-CON conferences were cited by the majority of the respondents as the items at which INCE excels. Next to this was the praise for our *Noise Control Engineering Journal*. Some of the responses noted the improvement of this publication over the last few years. It was good to see the membership recognize outstanding performance in two of the Institute's primary activities.

There were two areas that received some negative comments. These were the Board Certification program and the Technical Activities Committees. In the case of Board Certification, a few of the members felt this program did not provide value. One member was strongly critical of this program citing difficulties encountered in trying to go through the process. This is an issue which the Board of Directors must address.

With regard to the Technical Activities Committees, the primary issues were poor communication and some questions regarding the role of these committees. The Board of Directors has struggled with these same issues for some time. The results of this survey emphasize the need to examine what the role of these committees should be, how to make them a productive part of the Institute, and how to communicate their role to the membership.

There was good feedback on the move to electronic publications in general, seminars, marketing of the Institute, and more communication to the members by the President. This input presents opportunities to pursue to add value for the members and generate greater income for the Institute to minimize the need to increase dues or conference fees.

Overall, the feedback from the survey was very positive. The State of the Institute is great, but there is always room for improvement. With only a few specific issues cited, the Board and Officers can utilize this information and make specific improvements to the Institute and add value to our members. back to toc



James K. Thompson

2010-2011 President

Noise and Its Control

Marion Burgess

Asia Pacific Editor

It is particularly relevant to have a report in this issue from a symposium in Ottawa assessing various kinds of noise control technologies. The high number of papers at 2010 INTER-NOISE Congress held in Lisbon in June highlights the need for the application of noise control technology around the world. The CAETS (International Council of Academies of Engineering and Technical Sciences) forum held during the congress and organized by Tor Kihlman and Bill Lang, focused on worldwide noise sources. The report will be produced in due course but the forum provided another opportunity for discussions on the actions by governments and authorities that are necessary to ensure that noise control technology is applied.

While there is a good international agreement on damage risk levels, the challenge for regulatory authorities is to establish what levels of noise are acceptable for those in the community who are annoyed by noise. Noise control technologies are available for application to the majority of noise sources in the working environment which could reduce the extent of noise induced hearing loss as well as reducing the reliance on personal hearing protectors. Enforcement of noise exposure limits as well as information on noise control measures available can work together to achieve a quieter work environment.

The challenge is somewhat greater in relation to achieving an acceptable noise level in the community especially in residential areas. The subjective reaction to noise must be taken into consideration when establishing criteria or guidelines. This inevitably leads to the need for flexibility, and an understanding of the social context, in the establishment of such limits by the regulatory authority. Two examples highlight this need. In the days before the INTER-NOISE Congress, a festival in Lisbon led to celebrations throughout the night. This was clearly a special activity with widespread support in the community. The entire community was involved with the celebration and clearly enjoyed the associated "noise," and any attempts to apply noise control technology would not be welcomed. In contrast the noise from an outdoor concert may enjoyed greatly by those attending but the surrounding community may be justified in seeking application of noise control technology to reduce the noise impact for those not involved in the entertainment activity.

For many noise sources in the environment there are control technologies available that can be applied but may not be used until there is some enforcement by the regulatory authority. However managing noise in the environment needs an understanding that the reactions to noise include factors beyond the quantifiable or measurable noise levels.

The Swedish Acoustical Society

Svenska Akustiska Sallskapet or the Swedish Acoustical Society (SAS) was established in 1945. The current president of the society is Hans Jonasson, SP Technical Research Institute of Sweden, Borås. SAS publishes a journal, LjudBladet, three times a year. The journal includes acoustical news from Sweden but also papers of general interest. SAS also runs a web page, www.akustiska-sallskapet.org. Each year the board of SAS awards a prize, Ljudpriset, to an individual or an organization that has made significant contributions to promote a better acoustic environment. SAS encompasses all areas of acoustics. However, for vibration there is another society, SVIB.

SAS sponsors acoustical meetings all over Sweden. One meeting is the annual meeting of SAS and it includes several acoustical lectures. The location of this annual meeting varies from year to year. The last three years it has been in Gothenburg, Stockholm and Lund respectively. The 2009 Ljudpriset was awarded to the real-estate company Anders Bodin Fastigheter AB for pioneering work in building dwellings with very high sound quality. The company was first in Sweden to build with sound class A, which is two classes better than required by the national building regulations. For sound insulation this means 8 dB better. This is an interesting development. Thirty years ago all dwellings were built according to government building regulations, which, at that time, were considered to be adequate. Today, when many elderly people sell their one-family house in the suburbs to move to expensive apartments in downtown areas they expect and require a higher acoustical standard.

SAS is a member of the European Acoustics Association, EAA, the Nordic Acoustic Association, NAA, the International INCE and ICA. In 1990, SAS hosted INTER-NOISE 90 at Chalmers University of Technology in Gothenburg. The number of registered delegates at that congress exceeded 800 with participants coming from 39 countries. At INTER-NOISE 2010, 42 of the registered participants came from Sweden. Members of NAA are the five acoustical societies from Sweden, Denmark, Finland, Norway and Iceland. Iceland has the youngest society which joined NAA in 2006. The societies take turns hosting the Nordic Acoustical Meetings held every two years, which, the last few times, have been named Baltic Nordic Acoustical Meetings (BNAM) in order to encourage participation from the three neighboring Baltic countries. Many acousticians from Estonia are members of the Finnish Acoustical Society but otherwise our Baltic colleagues are not yet organized in national societies. The last time Sweden hosted this meeting was in Gothenburg in 2006. In 2008, it was in Reykjavik, Iceland, and 2010 in Bergen, Norway. The next meeting will be in Odense, Denmark. Because of the Baltic association BNAM is now held in English instead of in the Scandinavian languages so it is now also of interest to non-Scandinavian acousticians.

From 2011 a subscription with on-line access to the European journal ACTA ACUSTICA will be included in the membership fee .

This is the 72nd in a series of articles on the Member Societies of International INCE. This is an update of the profile that appeared in the 2001 September issue of this magazine.—Ed.

Member Society Profile is a regular feature of *Noise News International*. If you would like to have your society featured, please contact George Maling at inceusa@aol.com.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Dear Colleagues,

INTER-NOISE 2011, the 40th International Congress and Exposition on Noise Control Engineering, will be held in Osaka, Japan From 2011 September 4 through September 7. The Congress is sponsored by the International Institute of Noise Control Engineering (I-INCE) and co-organized by the Institute of Noise Control Engineering Japan (INCE/J) and the Acoustical Society of Japan (ASJ). The organizers and the Organizing Committee of the Congress extend a warm welcome to all prospective participants world-wide and invite all to join us in Osaka to discuss the latest advances in noise and vibration control engineering and technology, focusing on our Congress Theme of "*Sound Environment as a Global Issue*."

INTER-NOISE 2011 will feature a broad range of invited and contributed papers, together with plenary lectures by distinguished speakers. There will be extensive exhibitions of noise and vibration control technology, measuring instruments, equipment and systems from all over the world. Technical papers on the congress theme will be accepted with a special acknowledgement. Research papers in all other fields of noise and vibration are welcome.


Ichiro Yamada, Congress President

INTER-NOISE 2011 will be held at the Osaka International Convention Center (Grand Cube Osaka), directly connected to the Rihga Royal Hotel and easily accessible for international flights. Grand Cube Osaka is located close to the city centre of Osaka, which is the second largest city in Japan and is the center of commerce, culture, food, etc in the Kansai Area with many historical sites such as Osaka Castle. It is our pleasure to welcome you to INTER-NOISE 2011 and Osaka. We are sure you will enjoy all aspects of the Congress and Osaka. We look forward to meeting you in Osaka.

Sincerely,

Ichiro Yamada, Congress President
On behalf of the INTER-NOISE 2011 Congress Organizing Committee

First Announcement

Noise-Con 2011 INCE

The 27th annual conference of the Institute of Noise Control Engineering of the USA, NOISE-CON 2011, will run concurrently with the summer meeting of the Transportation Research Board, Committee on Transportation-Related Noise and Vibration (ADC40) on Monday through Wednesday (25-27 July, 2011). This conference is joining the overlapping transportation noise and vibration interest of the two organizations in Portland, Oregon to take advantage of the strong public interest and readily accessible public transportation project sites currently found in the Pacific Northwest.

The technical program for the joint conference will provide an opportunity for public and private organizations to share technical information on noise and vibration topics associated with high speed rail, light rail systems, highway surface and tire noise and aircraft noise to name a few. In addition, the technical program will include papers in areas such as *Experience with Measuring and Modeling of Wind Turbine Noise, Control of Noise Both Interior and Exterior to Buildings, Industrial Noise Measurement and Control, Product Noise Measurement and Control, Noise Measurement Equipment and Techniques, Structural Noise Transmission and Control and Community Noise Measurement and Control*.

Kerrie Standlee of Daly-Standlee & Associates, Inc. in Beaverton, Oregon will be the General Chair for the meeting. Hugh Saurenman of ATS Consulting in Los Angeles, California and Paul Donavan of Illingworth & Rodkin, Inc. in Petaluma, California will be the Technical Co-Chairs for the meeting.

An exposition of vendors of noise-control related materials, instrumentation and software companies will commence on Monday evening with a reception sponsored by the vendors and end on Wednesday morning at noon. A social gathering for attendees will occur at an off-site location to include special activities for conference members as well as family guests. A special accompanying guest program will also be included as part of the conference to encourage attendees to bring their families and consider the Portland conference as the beginning of wonderful vacation location.

Finally, NOISE-CON 2011 will celebrate the 40th Anniversary of INCE-USA by holding a special event to recognize the founding organizers and past presidents of the organization.

NOISE-CON 2010 Report: A Joint ASA and INCE/USA Conference

Baltimore, Maryland was the venue for NOISE-CON 2010, the 24th conference of the Institute of Noise Control Engineering. The first NOISE-CON was held in 1973. The meeting took place on April 19-21, 2010 the Marriott Waterfront Hotel, and it was held in conjunction with the 159th meeting of the Acoustical Society of America (ASA). This was the fourth meeting held in conjunction with ASA. The first was held in 1997 at the Pennsylvania State University. The second was held in 2000 in Newport Beach, California, and the third was held in 2005 in Minneapolis, Minnesota. For this meeting, Mardi Hastings of Georgia Tech served as the chairman of the ASA meeting, and Michael Lucas of Ingersoll-Rand served as the general chair for NOISE-CON. Courtney Burroughs, editor of *Noise Control Engineering Journal* edited the conference proceedings. Two hundred and ninety eight papers appear on the CD. Richard Peppin was the exposition manager, and arranged for 51 booths to be filled at the conference. The exhibition opened on Monday evening, April 19, and closed in the afternoon Wednesday, April 21. The list of exhibitors is available as a link from this page.

Since registration for the meeting was done by the Acoustical Society, and all registrants were welcome to attend both NOISE-CON and ASA sessions, it is not possible to determine the NOISE-CON only registration. However, approximately 2000 persons attended the joint meeting. 18 sessions were labeled as NOISE-CON only, and another 15 sessions were

Mike Lucasw and Mardi Hastings are happy that the joint meeting was a success.

Kenneth J. Plotkin

Todd E. Rook

Lilly M. Wang

organized jointly with INCE/USA and one or more ASA technical committees.

The first plenary session took place on Monday morning and was a presentation by Kenneth J. Plotkin of Wyle laboratories. The title of his talk was *Sonic boom: from bang to puff*. Abstract

The second plenary session of NOISE-CON conference featured a paper by Todd E. Rook of the Goodrich Corporation. The title of this paper was *Noise and vibration phenomena in aircraft wheel and brake systems*. Abstract

On Tuesday evening, all attendees at the joint meeting were treated to a buffet dinner in the hotel as part of the regular ASA social program.

The third plenary session was held on Wednesday morning and featured a paper titled *Effects of building mechanical system noise on the worker performance and perception* by Lilly M. Wang of the University of Nebraska—Lincoln. Abstract

A joint awards ceremony was held in the afternoon of April 21. Alan H. Marsh was presented with the INCE/USA Distinguished Noise Control Engineer award. The INCE Distinguished Noise Control Engineer award (DNCE) recognizes individuals who have rendered conspicuous and consistently outstanding service to the Institute and to the field of noise control engineering over a sustained period. Alan Marsh was *cited …for pioneering contributions to aircraft noise reduction, efforts to improve technical standards for sound level meters and for sustained service to INCE/USA*. The first group of INCE/USA fellows was also recognized at the awards ceremony. More information can be found on the Internat at http://www.inceusa.org/fellows.asp

Alan Marsh, right, receives the DNCE award from (now) INCE/USA president James K. Thompson.

Eric Baugh, left, and Jessica Gullbrand are recognized as recipients of the Hirschorn prize.

Jiri Tichy

Kent L. Gee

In addition, Mark A. MacDonald, Jessica Gullbrand, Yoshifumi Nishi, and Eric Baugh, INTEL Corp. were recognized as the winners of the 2010 Martin Hirschorn IAC Prize Best Paper Award of 5000 USD which was funded by the INCE Foundation. The award was for the best paper on new and/or improved cost-effective noise control and/or acoustical conditioning products published in the two years preceding the award. The paper appeared in Noise Control Engineering Journal, 57(4), 348-359, 2009, and was titled *Notebook blower inlet flow and acoustics: Experiments and simulations*.

A student paper competition was held in conjunction with NOISE-CON 10. Five students were awarded prizes of 1000 USD each which were funded by the INCE Foundation. The winners and their paper titles were:

Joseph Corcoran, Virginia Tech, USA
Output-only modal testing of simple residential structures and acoustic cavities using the response to simulated sonic booms and ambient excitation

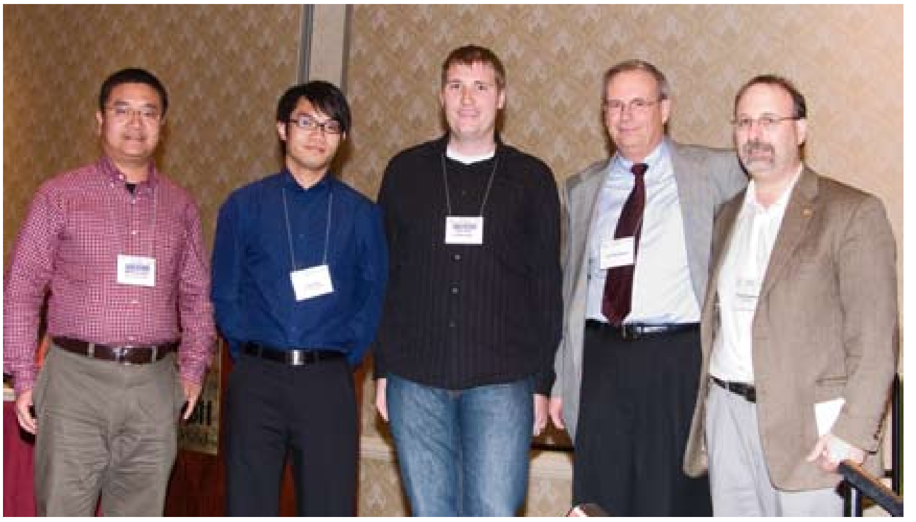
Tyler Dare, Purdue University, USA
Noise generation in contraction joints in Portland cement concrete

Jie Duan, University of Cincinnati, USA
A novel delayless frequency domain filtered-x least mean square algorithm for vehicle powertrain noise control

Wenwei Jiang, University of Cincinnati, USA
Two-substructure, Time-Domain Transfer Path Analysis of Transient Dynamic Response of Mechanical Systems with Nonlinear Coupling

Logesh Kumar Natarajan, Wayne State University, USA
Enhancing accuracy in reconstruction of vibro-acoustic responses of a complex structure using Helmholtz equation least squares based nearfield acoustic holography

Acoustical Society of America awards were also presented during the ceremony. Two major awards were presented to individuals with connections to INCE/USA. Jiri Tichy, 1987 INCE/USA president, was presented with the Society's highest honor, the Gold Medal.



Left to right, Student winners Wenwei Jiang, Jie Duan, and Tyler Dare with (now INCE/USA president James K. Thompson and Ralph Mueheisen, vice president for student activities and education.

He was cited …*for contributions to acoustic intensity measurement, active noise control, education in acoustics, and for service to the Society.* Kent L. Gee received the R. Bruce Lindsay Award. The award is given to a member of the Society who is under 35 years of age on January 1 of the year of the award and who, during a period of two or more years preceding the award has been active in the affairs of the Society and has contributed substantially, through published papers, to the advancement of theoretical or applied acoustics, or both. He was cited … *for contributions to the fields of jet noise propagation, nonlinear acoustics, and active control of fan noise*. In 2004, Kent shared the 5000 USD Martin Hirschorn IAC Prize with Scott Sommerfeldt for their paper *A compact active control implementation for axial cooling fan noise* which was published in Noise Control Engineering Journal. In 2002, he won an INCE/USA student paper prize for closely-related work.

A CD of the papers presented at NOISE-CON was also available at the conference. In addition to the 298 NOISE-CON 2010 papers, the CD also contains the papers from NOISE-CON 07 and NOISE-CON 08. More information on ordering copies of the CD can be found on the final page of this issue. Link

Worldwide Noise Sources

Janet Moss, Noise Control Foundation, Poughkeepsie, NY 12603

Introduction

A forum titled Worldwide Noise Sources was held in conjunction with INTER-NOISE 09 in Ottawa, Canada on 2009 August 24-26. The Ottawa forum was a follow-up to the 2008 June workshop on the design of low-noise vehicles for air, road, and rail transportation that was held at the Institute of Sound and Vibration Research, Southampton, U.K. in June, 2008. The report from that forum was published in the 2010 March issue of this magazine. This forum considered non-vehicular noise sources that present worldwide problems and will assess the state of noise control technology today. Noise emission goals for the future that will support sustainable development are recommended.

The purpose of the forum was to identify and prepare an inventory of the technology available today for the design of low-noise products and equipment and to assess what is needed to be developed in future technology for the reduction of noise emissions of these products and equipment. This technology assessment will provide the the International Council of Academies of Engineering and Technical Sciences (CAETS) with an update on the state of noise control technology so that CAETS may support recommendations to be developed by the CAETS Noise Study Committee on the noise issue. *(See the President's Column in the March issue of this magazine.—Ed.)* These recommendations will encourage the use of low-noise noise vehicles, machinery, and other products and promote their use throughout the world.

This forum considered non-vehicular noise sources in occupational, domestic, and community settings and concluded with a roundtable to discuss recommendations on control of worldwide noise sources for a statement to be circulated to policy-makers by CAETS. The forum ran in parallel with the technical sessions of INTER-NOISE 2009 following the morning plenary sessions.

Low Noise Machinery and Low-Noise Products

The first session was devoted to low-noise machinery and equipment for workplace and community. This session was devoted to the design of products, machinery, and equipment that are sources of noise in occupational, domestic, and community settings. Included were the "basic" mechanical components (engines, pumps, fans, compressors…) and a "green" source of power.

The second session was devoted to low-noise products. During this session the focus was on the design of low-noise products and equipment (stationary production equipment in manufacturing plants, consumer products and household appliances, off-road recreational vehicles, and office equipment).

Session 1 and 2 Panelist Questions

1. For your product how important is the low-noise criterion compared to the other performance criteria such as robustness, energy efficiency, design, and price?
2. What is the extra cost (percentage of the cost) to produce a low-noise product versus a product where noise is not a consideration?
3. Where do the requirements for low-noise products come from (regulations, management, purchasers, end-users, or other manufacturers integrating the products)?
4. How are relations managed between the manufacturers of noise-generating components (motor, compressor, engine, muffler, damper…) and the manufacturers of complex machines integrating them?
5. How many people are involved in noise research and development in your company (for measurement, design, prototyping, control…)? Is this work subcontracted to consulting firms, research and development institutions, or universities?
6. What test facilities are used in the design of your company's product (specific test rigs to 'load' the machine, acoustic rooms…)?
7. What tools and software are used for noise measurement and analysis?
8. Is the concept of 'subjective sound quality' a concern for the product your company produces? If the answer is affirmative, which metrics do you use?
9. If you perform measurements of competitive products, how do your company's products rank?
10. Are noise measurements performed in your company's production control process?
11. During your product development process do you study noise-generating mechanisms and/or the physics of sound transmission and radiation?

12. Do you characterize the noise emissions (airborne, structureborne, or fluidborne sound) of the mechanical/electrical components that your company manufactures or that are integrated into its products? How is this done?
13. Do you characterize the performances of any noise-attenuating devices (isolators, mufflers, silencers, enclosures, cabins…) that are integrated into the company's products? How is this done?
14. What tools are used to identify sound sources and analyze sound paths and their control?
15. During the paper phase of the design of the product, what tools and software do you use and do they integrate vibration and acoustics predictions?
16. Do you use specific tools and software for noise prototyping?
17. Is the metric currently used to describe the outdoor noise emission of your product an adequate representation of the low frequencies radiated to adjacent buildings?
18. Is the noise emitted by the power source for your product a significant contributor to the overall noise emission of the product?
19. Is retrofitting in situ to reduce the noise of older equipment that has an additional effective lifespan a feasible option for manufacturing plants?
20. What information does the purchaser of low-noise home appliances need? Are the metrics currently used to describe the noise emissions of these products satisfactory?
21. Is the engine the principal noise source of off-road recreational vehicles (motorcycles, snowmobiles, all-terrain vehicles, jet skis, pleasure watercraft, and ultra-light or micro-light aircraft)?

What are the principal sources of equipment noise in offices and the means to reduce their noise emissions at the source?

Building Noise

The focus of this session, Session 3, was on the design of buildings (including "green" buildings) and the construction products and materials developed to provide low-noise environments. Recommended practices and building codes were considered.

Session 3 Panelist Questions

What advances have been made in the technical understanding of sound transmission in buildings in recent decades? What major technical challenges impede systematic and correct prediction of the sound reaching building occupants from specific sources?

1. What elements are needed to implement the scientific understanding of sound transmission in the systematic design and evaluation of buildings to meet occupant requirements? *(such as technical standards for measuring performance of the building, standards for evaluation of subsystem performance, methods to integrate data on subsystem performance, credible information sources).*
2. What is needed for an effective regulatory system for the acoustical performance of buildings? Are there gaps in the available measurement standards or the subjective criteria on which to base regulations?
3. How are building codes enforced (in Europe, in North America, elsewhere)? What barriers impede a common international approach? *(harmonized technical standards, common performance criteria, historic concerns, etc.)*
4. What advances in a system approach have been made to minimize the noise of equipment in commercial buildings and homes? How do differences between heavy and lightweight construction (concrete and masonry versus lightweight framed systems) affect such transmission? Are separate approaches needed for building services (plumbing, HVAC, etc.) and for occupants' appliances such as dishwashers?
5. How can the noise generated by machinery and equipment within a building be controlled by a building code or other regulations? Are enhanced technical standards needed? *(source emission versus noise at receiver and related gaps in knowledge and tools)*
6. What special issues create the need for extensions beyond the conventional approach to sound insulation based on average sound power reaching a space. *(speech security, low-frequency issues, etc.)*
7. As low-frequency noise and vibration from arterial traffic must be minimized in adjacent commercial buildings and homes, what special noise and vibration control treatments have been found to be most effective?
8. What are the advantages and disadvantages of a "green" building design framework in providing a satisfactory acoustical environment for the occupants?
9. What new advances for noise control in buildings are anticipated during the next decade?

Codes, Practices, and Standards for Low-Noise Machinery and Equipment

This session, session 4, addressed recommended practices, labeling, noise declarations and requirements, and the limitations of current standards as well as future needs for standardization, test codes for products, machinery, and equipment.

Session 4 Panelist Questions

1. How can international test standards be more "user friendly"? Background for question – There is a

growing concern that it takes a Ph.D. in acoustics to not only understand the test code, but also to be able to apply it. The standards produced by ISO Technical Committee 43 (acoustics) and its Subcommittee 1 (noise) are complex and many of them require advanced formal training in acoustics to understand and implement. The standards produced by TC 43/SC 1/Working Group 28 (Basic Machinery Noise Emission Standards are good examples. An untrained person would have great difficulty in making measurements according to the International Standards prepared by Working Group 28.

2. How can we involve consumers and the public in the ISO and IEC standards development process?
   Background for question – Involvement will ensure that public interests are being considered. There are many reasons these standards are so complex, but perhaps a principal reason is the ISO/IEC standards development process itself. Financial support to participate and attend meetings comes from industry and government agencies. The developers of the standards are academics, government employees, manufacturers' representatives, and consultants; but the public is not represented in the ISO development process. By contrast, the American National Standards Institute (ANSI) encourages participation of representatives of the public on standards working groups by permitting their comments on draft standards with the requirement that those comments be addressed. ANSI S-committees on acoustics and noise administered by the Acoustical Society of America have a category of membership representing consumers, i.e., the public. In the ISO development process, international standards are produced for measuring sound levels to a small fraction of a decibel while many elected representatives of the public who legislate regulations have difficulty deciding on required sound levels to the nearest 5 or 10 decibels. This will not be easy to correct.

3. How do we ensure that manufacturers do not "cheat" on or misrepresent the noise declarations of their products?
   Background for question – There are several possible ways to correct this situation:
   a. Apply the correct "K" factor (to account for product variability, measurement method variability, and manufacturer's risk).
   b. Certify by an independent authority that the tests were conducted according to the relevant standard (for example, not testing at temperatures less than the lower end of a standardized temperature range for a product with fan speed control or not measuring emission sound pressure level at "bystander positions" instead of a nearby operator position).
   [Alternate question] Is there evidence that some manufacturers have misrepresented the noise declarations of their products? If so, how can we ensure that manufacturers do not "cheat" on their noise declarations?

4. How can we ensure that test standards enable or encourage the application of technology without ambiguity and do not stifle innovation by acting as barriers to the implementation of technology?
   Background for question – Some current International Standards conflict with one another in their descriptions of operating procedures and test conditions for similar noise sources. The International Standards need to be revised to clarify the use and applicability of individual standards.

5. What new measurement standards are needed? What current measurement standards need major revision to improve their usability?
   Background for question – The measurement standards for some industries are highly developed and updated in a timely fashion (e.g., information technology industry), but the standards for the products of many industries are at an early stage of development.

6. How do we handle the confusion of consumers between sound power level and sound pressure level and the even more confusing use of the decibel as the unit of measure for both sound power level and sound pressure level?
   Background for question – This confusion has been known and discussed for decades. The information technology industry has adopted a simple solution to this problem, but other industries have failed to follow suit.

7. In terms of product noise declarations (labels, tags, on-line information), actual numbers are important and useful for characterizing the noise emission levels, but how can we best get "comparative" noise-level information presented to a consumer on how one product compares to other products in the same family?
   Background for question – This question raises supplementary questions:
   a. How can independent authorities collect or "certify" the "range of levels for similar products" that would be necessary for such a comparative noise declaration?
   b. Anticipating that establishing such range-of-levels for the many product types and sub-types will take years, how can we best present comparative information in the interim for products that lack established ranges?

8. With respect to product noise declarations what about products that are loud enough that an additional concern (and perhaps the only

concern) is as a “Noise Hazard” with the potential for hearing damage?
Background for question – This question raises supplementary questions:
a.What kind of safeguards would be effective? Warnings? Labels? Noise Hazard Symbols? Information to lower risk?
b.What can a manufacturer do to best communicate these safeguards to the public or prospective purchaser?
c.Should a product noise declaration with “Noise Hazard” information be different from the normal product noise declaration for products without risk for potential hearing damage? In what ways should the declaration be different?

SESSION 1: Low-noise Machinery and Equipment for Workplace and Community

Panelists

- **Jean Tourret,** France, Session Chair
  Overview of the machinery and equipment noise issue
- **Raj Singh,** Ohio State University, U.S.A.
  Design of low-noise mechanical components
- **Steve Marshall,** Baltimore Air Coil, U.S.A.
  Challenges in the design of low-noise refrigeration compressors
- **Marco Beltman,** Intel, U.S.A.
  Design of low-noise fans and air-moving devices
- **Serguei Timushev,** Moscow, Russia
  CFD programs for pumps and fans, acoustic optimization
- **Michael Dittrich,** TNO (presented by Frits van der Eerden, TNO) The Netherlands
  Low-noise design of complex machines using specific software
- **Mark Bastasch,** CH2M Hill, U.S.A.
  Design of wind turbines and farms

Presentations

Jean Tourret – Overview of the machinery and equipment noise Issue

This overview is from the perspective of the French Mechanical Industries (about 7000 companies that are diverse in size and products) which represent a wide spectrum of problems to be solved in many domains of industrial noise and vibration control.

These companies are confronted by two main types of noise and vibration problems:

- Designing and manufacturing better *products* in terms of low noise and vibration performance.
- Reducing noise and vibration of *production tools* for workers, machines and environment.

Most of the effort (> 90 percent in terms of money) is concentrated on the first issue. This is due to the current economic impact of low-noise products in Europe, enforced by new regulations and strong competition.

Designing and Manufacturing Better Products

A product which is noisier than its competition will not find a market! A survey of products manufactured by the mechanical industries has shown that approximately 50 percent of those have noise and vibration issues. Those products can be classified in three main categories for which different strategies apply: "active" mechanical components; machines, appliances, and equipment; and mobile machines and vehicles

“Active” Components

These include gears, mechanical transmissions, hydrostatic transmissions and actuators, hydraulic pumps and valves, air compressors, refrigerating compressors, fans, air moving devices, internal-combustion engines, and electric motors.

There are generally no regulations concerning the noise emission of components but there may be specifications given by “integrators” to suppliers.

The manufacturer may have to provide specific vibro-acoustic data: vibration levels at key points, pressure pulsations in pipes or ducts, and sound pressure levels/sound power levels. These data are measured under load on a classical test rig used for the tests of the product or on a sound–proofed rig in order to reduce the effect of extraneous sources. Depending on the production volume, measurements are systematic or very limited and are performed by the control laboratory.

If the manufacturer decides to improve the product or develop a “silent” one, the task needs strong involvement of the design office. Advanced studies on the noise generated by components needs a detailed knowledge of machines, mechanics, and fluid mechanics which has a higher priority than knowledge in noise and vibration

Machines, Appliances and Equipment

These represent a diversity of products such as portable electric tools, computers, medical devices, domestic appliances (washing machines, refrigerators), boilers, air handling units, machine tools, textile or printing machines, food processing, packaging, chemical processing, and power units. Many of these machines are covered by standards or regulations concerning their sound emissions to the users or to the environment.

Noise "labelling" puts commercial pressure on several types of products to become quieter and the manufacturers have to provide information about the noise emissions of their products.

Sound measurements based on specific test codes have to be performed under controlled conditions in terms of load or acoustical environment (anechoic or reverberant rooms for small machines, free field or sound intensity for large units).

Noise and vibration are generated either by the "active" components (and then frequently amplified by the structure of the machine) or by the process itself (cutting, grinding, flow).

Reducing noise and vibration requires a broad knowledge: process(es) involved, vibroacoustic performances of "active" components (seen as black boxes generally), structural dynamics and rotor dynamics, general tools for vibration and acoustic analysis and modelling, systems and materials for noise control (intake, exhaust, and ventilating silencers, enclosures, vibration isolators, damping, and absorbing systems). The manufacturer has to permanently improve the vibro-acoustic performances but the effort depends a lot on the type of application (for example, HVAC machines and home appliances are considered as more "sensitive" than machine tools.)

Mobile Machines and Vehicles

This covers agricultural tractors and machines, earth-moving machines, handling trucks, cranes, and also transport vehicles like rail-vehicles, ships, light and heavy trucks, and busses. The noise issue concerns both the noise produced outdoors and the acoustic comfort inside the vehicle for the driver and the passengers. For outdoor noise, strict regulations exist (such as in the outdoor machinery European Directive) that require information on sound emissions and impose limits. Rather complex measurements are performed in many cases by official laboratories but manufacturers have to check in advance the result which may need costly installations and tests. For internal noise, measurements are performed at the working position in the cabin (at the operator's ear using classical methods), and at the passenger position in transport vehicles.

The noise is generated primarily by the power-train system but also, for vehicles, by the rolling process which is strongly dependent on the rail or road surface. Reducing noise and vibration needs a extensive knowledge of the primary sources (engine, gearbox, hydrostatic transmissions, cooling fans), the secondary sources (air conditioning, rolling noise, aerodynamic noise), and mufflers, ventilating silencers, enclosures, encapsulation, vibration isolators, damping and absorbing materials and include active control, vibro-acoustical analysis and modelling, and sound quality techniques.

For the three categories of products, manufacturers cope with noise problems in very different ways. In many situations they partly or totally subcontract the R&D to a specialized consulting company or do it in association with a university. Only a small number of manufacturers (specific units of large companies or some large Single Market Enterprises) can handle by themselves the development in noise control and have their own dedicated labs and equipment.

Reducing Noise and Vibrations of the Production Tool

This includes two main objectives: Reducing noise and vibrations for the operators inside workshops, and reducing noise and vibrations outside the factory for the neighboring environment.

Reducing Noise for the Operators Inside Workshops or Factories

This activity has increased significantly over the last 30 years. It has now become a major objective for production factories and plants under the pressure of relevant European directives which impose noise limits at the work station.

In the mechanical industries most manufacturing processes and machines are involved: forging, forming, grinding, sheet metal working, punch presses, lathes, and high speed mills.

The situation is similar in most other industrial sectors like woodworking, plastic working, food processing, as well as in the building construction sector.

The most efficient way to reduce noise is to do so as close to the source as possible. The more "elegant" way consists in improving the process or in replacing the machine with a more silent one which is quite uncommon. The more classical and efficient alternative is to use total or partial enclosures with efficient vibro-isolation and silent ventilation. Another alternative is to introduce sound absorbing ceilings and walls together with absorbing screens. The last alternative is to use individual hearing protectors.

Reducing Noise for the Neighboring Environment Outside the Factory

This has now become a significant objective for production factories and plants under the pressure of relevant European directives which impose noise limits in the environment. The noise outside the building is reduced by noise control measures inside but it can be further reduced by using highly-isolated wall panels and doors and by controlling separately the émission of outside sources. Prediction tools exist to optimise the sound insulation of the building.

The means dedicated to reducing the noise of production tools are generally limited financially. With the exception of very large companies there is usually no specific staff to handle the problem of noise reduction inside or outside of the factory. The problem is then subcontracted to an acoustic consultant as well as to a manufacturer of enclosures and silencers or to a building contractor and to suppliers of specialised absorbing or insulating materials. In many situations this activity is supervised by the safety and health department or by the building maintenance and construction department of the company in which one of the staff has been trained at an elementary level on acoustical measurements, sound propagation, and building acoustics. It is not uncommon in medium-sized companies to have a sound-level meter for control purposes.

Raj Singh – Design of low-noise mechanical components

Introduction

Noise from machinery, equipment, products, and vehicle components comes from a collection of machine elements, mechanisms, and actuators, including gears, brakes, belts, bearings, clutches, etc. Many common physical characteristics lead to vibration sources, including multiple periodicities and modulations. Source strengths are also strongly influenced by key non-linear characteristics such as clearances, dry friction, multi-valued springs, etc.

Common Machinery Noise Source Features

To begin identification of sources (with focus on vibration sources), one should identify frequencies or periods based on kinematics; also, relate peaks/impulses and periods to physical events or processes. Then, conduct force and motion analyses on the dynamics of machine elements. Further, examine multi-dimensional motion coupling, vibration modes and resonances, dynamic interactions between machine elements, and mobilities of sub-systems. Typical excitations of periodic forces/torques include rotating and reciprocity unbalance, misalignments, eccentricities, pulsating pressures, torques, electro-magnetic forces, etc., vortex shedding, passage/contact frequencies, unstable operations, etc. Typical excitations of periodic motion sources include harmonic drives and linkages, deviation from kinematic conjugacy (gears, splines), surface waviness and finish, eccentricities, eccentric cams, out of roundness, etc., and motion from other components.

Side-band Structures

As an example, consider spectral modulations or side-band structures that are commonly found in rotating systems (such as gears, bearings, fans, tires, motors, etc.). Modulated spectral contents are of importance from noise and vibration control and health monitoring (fault detection) perspective. Modulations affect perception metrics when monitoring sound quality. The existence of frequencies can be explained by several theories (Kinematic, Fourier, Communication) but the amplitude behavior including an asymmetric nature (or disappearance) of some side-bands is not well understood. The force modulation concept and dual-domain periodic, non-linear differential equation seem to offer better explanations. New or refined active control of multi-spectral contents, should one engage in the suppression of amplitude or frequency modulated type signals?

Noise Source Analysis Using Linear System Theory and Some Complications

Frequency response functions (based on the linear system theory) are often used to examine vibro-acoustic issues in the frequency domain (ω). Conceptually, the single input and single output relationship, as given by $X(\omega) = H(\omega) F(\omega)$, is the simplest model; here, $F(\omega)$ is the excitation in frequency domain, and $f(t)$ is the excitation in time domain; $X(\omega)$ is the vibro-acoustic response, and $H(\omega)$ is the transfer function from source to receiver. Complications include the fact that many internal sources (inputs) exist and interact with each other, and source regime(s) include amplification elements (such as resonances). Also, source spectra are modulated. Deviation from the linear system theory would bring in non-linear elements (dry friction, clearances) and time-varying parameters (such as spring and damping). Lastly, sources interact with structure-borne paths.

Some Non-Linear Vibration and Noise Sources

Among non-linear vibration and noise sources are clearance, dry friction, sliding friction in gears, and multi-valued springs/dampers. Clearances can be found in torsional geared systems, belts, bearings, etc. Clearances generate rattle or clunk type noise problems. Dry friction affects brakes, driveline systems, belts, etc., which can lead to stick-slip induced vibration, noise, and instability. Sliding friction in gears is also a source of gear noise. Multi-valued springs/dampers, which include fluid mounts, actuators, and active materials, can experience amplitude and frequency-dependent stiffness or damping. Many noise and vibration source regimes are also defined by non-linear, time/spatially-varying differential equations. As an example, brake groan (stick-slip) events follow a set of non-linear dynamic regimes corresponding to several stick-slip frequencies of friction coupled systems.

Reduction of Machinery Noise Sources

The generic principles of the reduction of noise sources include two key factors: steady state noise and transients and vibro-impacts. To reduce steady state noise, reduce source strengths by balancing parts, minimizing misalignments and eccentricities, etc. Also, choose relatively quieter elements. Improving contact regimes to reduce dynamic loads and providing proper lubrication will help reduce friction-induced sources. Avoid resonances where possible, and (changes in natural frequencies; reduce coupling) use structure-borne path control methods (isolators, damping, absorbers, mobility mismatch, etc.) without changing the sources. In reducing transients and vibro-impacts, make certain to avoid impulsive excitations or sharp discontinuities by adding preloads or incorporating system elements that reduce impulsive loads. Typically, one should smoothen excitation time histories (increase pulse width, reduce peaks), and change the repetition rate if possible.

Contemporary Design Trends

Most of the design trends or schemes enhance the strength of noise and vibration sources. For instance, some energy efficient devices are just more noisy; faster operations (higher speeds or power densities), compact devices, switchable modes (leading to transients), "easier" assemblies (rattle and squeak type problems), etc. lead to noisy products.

Recommendation for Research

The long term research issues (from a personal perspective) include a better understanding of machine element noise sources (especially non-linear sources such as gaps, dry friction and time/varying parameters). New or improved multi-disciplinary models are needed (contact mechanics, surface mechanics, machinery vibro-acoustics, computational issues, flow-sound-structure coupling, etc.). Novel ways to control noise, shock, vibration problems (especially transients) must be found. These would include the design of systems with "intentional" non-linearities, better system design concepts, and the employment of active (smart) materials.

Steve Marshall – Challenges in the design of low-noise refrigeration compressors

Refrigerant compressors serve as the engine for the refrigeration cycle. Applications for refrigerant compressors vary from household appliances for food preservation, heat pumps and single-room cooling to industrial refrigeration and air conditioning. The sizes for refrigerant compressors range from fractional kilowatts to several hundred kilowatts of power. Compressor designs fall into two main categories: dynamic and positive displacement. An example of a dynamic compressor design is the centrifugal compressor common in large commercial air conditioning. The three types of positive displacement compressors are the reciprocating, the rotary, and the orbital along with their derivatives.

Stage III of EC Directive 2000/14 limits the sound power to 97 dB re 1pW for 'any machine that compresses air, gases, or vapor to a pressure higher than the inlet pressure' and operates up to 15 kW of power. For compressors operating at power higher than 15 kW, the sound power is limited to 95 dB + 2 log (power). Although the directive serves as a good starting point, the compressor applications affected by the directive are far too broad than for the directive to command much influence. Therefore, compressor noise levels will continue to be limited by market competition and industry self-regulation.

The Air-Conditioning, Heating, and Refrigeration Institute (AHRI) is the U.S. trade association representing manufacturers of air conditioning, heating and commercial refrigeration equipment. AHRI standards and guidelines are used throughout the world. AHRI provides access to its standards and guidelines, as well as information about how the standards are developed and advanced globally. Through the use of industry standards and certification programs, consumers can be assured manufacturers' performance claims are accurate and rated uniformly, enabling fair comparisons.

The purpose of AHRI Standard 530-2005 is to establish for the rating of sound, vibration, and pulsation for refrigerant compressors: definitions; test requirements; rating requirements; minimum data requirements for published ratings; and conformance conditions. As part of Standard 530-2005, sound tests shall be conducted in a free field in accordance with ANSI Standard S12.35 or in a reverberation room meeting the requirements of ANSI Standard S12.51 [ISO 3741]. Sound power levels shall be determined in decibels with respect to 1 pW for the one-third octave bands.

Compressor manufacturers are also mindful of test standards addressing sound levels produced by the equipment that host the compressors. For example, the purpose of AHRI Standard 270-2008 is to establish for outdoor unitary equipment definitions, requirements for testing and rating sound, marking and nameplate data and conformance conditions. The ratings shall be comprised of octave band sound power levels, overall A-weighted sound power level, sound quality indicator (SQI) per ARI Standard 1140 (optional), and one-third octave band sound power levels (optional).

The purpose of AHRI Standard 1140-2006 is to establish sound quality evaluation procedures for air-conditioning and refrigeration equipment. The procedure is derived from the work of Wells and Blazier, "A Procedure for Computing the Subjective Reaction to Complex Noise from Sound Power Data," ASHRAE 1963. One-third octave band power levels are weighted to adjust for psychoacoustic sensitivity to frequency and discreet tones; they are then converted to a single number, Sound Quality Indicator (SQI).

Compressor manufacturers face two major design challenges that affect sound levels: environmental-friendly refrigerants and energy efficiency. Next year, consumption of hydrochlorofluorocarbons (HCFCs) must drop another 40% of 1989 consumption levels. Alternate refrigerants must meet strict new requirements in terms of ozone depleting and global warming potential. Compressors of most alternate refrigerants must operate at higher pressures. The higher pressures cause greater dynamic forces and gas pulsation. Dynamic forces and gas pulsation are the sources of unwanted sound and vibration in a refrigerant compressor. Advances in attenuation methodology must accompany alternate refrigerants.

In addition to increasing the dynamic forces, alternate refrigerants possess an inherently higher speed of sound, and thus longer wavelengths. Longer wavelengths make reactive muffler design more challenging due to geometric size restraints. The alternate refrigerants also suffer from low oil miscibility. As a result, the mechanical components of the compressor are insufficiently wetted for lubricating bearing surfaces and adding vibration damping. Also, to prevent oil from exiting the oil-refrigerant mixture and then pooling downstream of the compressor in the refrigeration circuit, oil separators are often added to the compressor. The oil separators generate considerable noise of their own.

Energy efficiency poses the second design challenge to compressor manufacturers. In addition to increasing energy efficiency, variable speed operation reduces overall sound exposure and annoying cycling. However, the variable-frequency driving forces are certain to excite a structural or acoustic resonance. Energy efficiency also calls for shorter, more direct gas paths through the compressor. The short flow paths prevent using gas cavities as acoustic mufflers or plenums. If the compressor design incorporates valves, the valves must be stiffer and valve seats must be thinner to prevent inefficient back-flow. Stiffer valves contacting thinner valve seats create higher levels of valve slap noise. Finally, energy efficient oil-less compressor designs (pumping or sloshing oil draws power) eliminate the sound and vibration reducing properties of the oil.

The pursuit of improved energy efficiency also affects the sound environment adjacent to the compressor. For example, the fastest growing segment of the air conditioning – heat pump industry is the mini-split systems. The compressor in a mini-split system is positioned just outside of the occupied space rather than at the end of a long system of air ducts such as in previous unitary applications. Energy efficiency is also achieved by lengthening heat exchanger coils. The increased coil surface area provides greater sound radiation potential for gas pulsation from the compressor.

In order for consistent sound reduction across the operating range of a variable-speed compressor, attenuation devices must be developed with broadband response. A compressor intake muffler was designed that applies the absorptive properties of melamine foam for broadband pulsation reduction. The melamine foam was discovered to uniquely survive the harsh environment of a refrigerant compressor.

Improved test and analysis methods are needed by compressor sound engineers for addressing the design challenges. Dynamic pressure transducers, similar to microphones, measure a scalar quantity representing the sum of the traveling waves. A method was recently attempted for separating the positive- and negative-traveling pressure waves in the refrigerant circuit. Digital signal processors acquire and calculate the transfer function between two dynamic pressure transducers. Phase calibration between the transducers is required.

Marco Beltman – Design of low-noise fans and air-moving devices

Information technology products are high volume products, and components will typically be used in various system configurations. The main design considerations for these systems are performance, cost, size, power consumption, and acoustic noise. The relative importance of these vectors varies per segment. The main acoustic drivers are usage models, customer returns, eco labels and purchase specifications and competition. The information technology industry has an extensive set of standardized test codes in place for measurements, operation, verification and declaration of noise emissions, including harmonized ECMA, ISO and ANSI standards. Advanced techniques are used to develop quieter fans and the comprehension of inlet, installation and mounting effect is critical. Numerical simulations for air flow are feasible, but acoustic prediction models as design tools remain a challenge. Fan speed control has found widespread adoption, resulting in significantly quieter systems. Even though acoustical benefits of active noise control have been demonstrated, the cost and size impacts remain a barrier for widespread adoption of this technology. Extensive sound quality studies indicate that the sound level is the main parameter governing annoyance, but that tonal content is important and that geographical variations are significant.

Standardization

The information technology industry has long history of developing standardized test codes. The basic metric is the emitted sound power level, based on the fundamental ISO 374x standards, supplemented by operator/bystander sound pressure levels, based on ISO 11201. Specific information technology test codes, such as the 10th edition of ECMA-74, include specifications for operating conditions and include two methods to assess the presence of pure tones. ECMA 109 outlines a method for declaring sound power level to cover lab to lab and system to system variations. The information technology industry strives for harmonization of standards worldwide. Therefore ECMA, ISO and ANSI equivalent standards are periodically reviewed and updated to ensure one standard worldwide that is current and relevant.

Infrastructure

An extensive infrastructure is in place for acoustic technology development, including anechoic chambers for acoustic sound power and sound pressure tests and low noise measurement systems to accurately determine the emission for quiet components. Source identification is also addressed through more advanced techniques such as acoustic holography, scanning laser Doppler velocimetry and laser particle image velocimetry. Finally, subjective perception is studied through binaural recording, analysis and playback

Technology Development Status

In order to address the source emission from fans and air moving devices the ISO 10302 fan plenum was developed to quantify the impact of backpressure on the acoustic emission. Recent advances have extended this approach to include inlet and mounting effects. For example, in notebooks the air moving devices are typically located in a small gap between parallel plates, impacting the inflow and exhaust conditions. This has a significant impact on the air flow, and the acoustic characteristics. Optimization of the design for operating conditions rather than free flow shows that a 2-5 dB benefit can be realized. Prediction and optimization of the air flow of fans is feasible with numerical models, but acoustic simulations remain challenging. Although progress has been made in predicting parts of the noise spectrum of low speed fans, a prediction of the overall spectrum and the application as a design tool remains elusive. Therefore, numerical techniques are complemented with experimental techniques such as particle laser velocimetry, which allows capturing transient flow fields and correlating flow phenomena to acoustic noise generation.

Extensive sound quality studies are conducted to identify and quantify the parameters that govern the subjective perception for information technology product sounds. An example study quantified the annoyance level to sounds from personal computers in multiple geographies. The results demonstrate that the sound level is the main parameter, but that tonal content is important and that geographical variations are significant. It is therefore important that metrics and procedures for the identification of pure tones are already included in the information technology test codes.

In addition to the source emission itself, the installation in a system is very important because of changes in source character and coupling to enclosure acoustic modes. In addition, vibration coupling may result in increased noise, but this is typically a smaller effect. Fan speed control has found widespread adoption, and based on temperatures and loads may reduce the acoustic noise by as much as 15 dB. Also, the benefits of active noise control has been demonstrated, in which reductions of 5 to 10 dB were obtained, but cost and size aspects remain a barrier for widespread adoption of this technology.

Serguei Timushev – CFD programs for pumps and fans; acoustical optimization

The presentation is on bounded rotating bladed pumps (and ventilators) with subsonic flow. To this type one can relate axial, radial, and diagonal pumps and fans, water-jets, other types of home equipment like the lawnmower, vacuum cleaner, miniature wind turbine (installed just on the roof of the house, etc.) To get the level for further discussion and evaluation of ideas, methods, and software, the main goal of CFD-CAA application to the pump and ventilator noise problem must first be established.

Industry people—engineers, researchers, manufacturers—are using CFD-CAA methods and software capable of predicting absolute levels of pressure pulsations and sound power in the near field of rotating bladed machines with accuracy +/- (3..4)dB. The processing time will be an important requirement as well. They need days for a computational test, not weeks or months.

The definition of the noise prediction problem is common for all types of bladed rotating machines. It is tightly linked to pressure pulsation spectra. One can see a set of tonal components of different nature and usually proportional to the rotor angular speed. Generally BPF components dominate in the spectrum. There are combined components and known cases where combined component dominates in pressure pulsation spectrum.

Small-scale turbulence and other weakly correlated unsteady phenomena connected with back-flow and vortex-shedding generate a wide brand spectral component (pedestal). Cavitation is a well-known source, but one can say the cavitation phenomenon is a very special case as the pump in a normal operation mode must work without developed cavitation, and even in the stage of cavitation inception the noise frequency is out of human audibility range. Thus one can put it out of consideration, anyway it stays as a big challenge for CFD-CAA modeling. It is well known that from the first critical mode (when the head starts to drop) pressure pulsations including BPF tonal components begin to increase due to the effect of caverns presence in the flow path.

The most important feature of rotating bladed machines is the acoustical (or propagating) part of the pressure pulsations exhibits a resonance behavior that from one side depends on the circuit characteristics and from the other side, on the acoustic resonances of the flow path and phase characteristics of excitation (e.g. ratio of number of impeller blades to number of diffuser vanes).

One can state that pressure pulsation field consists of two zones. The first zone (zone of pseudo-sound) is located near the rotor. The amplitude of pressure pulsations in this zone links to the blade loading. The nonuniformity of flow parameters rotating with the rotor generates tonal sound. The amplitude of pressure pulsations in the pseudo-sound zone rapidly attenuates with increasing distance from the rotor. Generally in 15-20% of the centrifugal impeller radius the BPF amplitude drops by an order of magnitude. In the flow path one can discover very close locations where pressure pulsations amplitude differs by an order of magnitude that gives big gradients of flow parameters.

Features mentioned above bring a rather complicated picture of pressure pulsations in the flow path where near the rotor one can see a pseudo-sound behavior with higher pressure gradients and accompanied acoustical domain where pressure pulsations field appears as a result of phase interaction, interference on the walls and with acoustic impedance of the circuit. Even for the simple volute geometry one can get an acoustical behavior in the outlet part with amplification of a BPF harmonic due to the acoustic resonance. In the axial type machine one can see that within a distance of rotor radius from blade edges, pressure pulsations exist in the form of higher-order radial-tangential modes. These modes rapidly attenuate passing through intermediary modes to the first tangential mode, which transforms to a plane wave.

Based on a brief review of last decade publications one can state a rather big difference in methods to predict pressure pulsations and noise in pumps and ventilators. Speaking more precisely, there are mostly no attempts in recent studies (at least opened to the public) to predict hydraulic noise generation in pumps (excluding AVM approach). But it is not enough to model and optimize adequately sound generation and propagation in pumps. Thus for pumps one can state a 1D wave equation solution method published by Chen almost 50 years ago that can be used if appropriate boundary conditions in the form of acoustic disturgances will be supplied. The source of inhomogeneous wave equation is the key issue of theoretical background.

There are many methods and programs used in fan noise modeling but most of these methods are based on Lighthill's equation analogy with far field approximation. Actually this equation initially was proposed by Lighthill more than 40 years ago for the case of small-scale turbulence and there is no decomposition procedure. In a task of practical optimization this problem inevitably poses a question regarding the source evaluation.

The decomposition problem (on to vortex-mode and acoustic-mode) can be resolved by using the LEE approach, but decomposition must be completed for boundary conditions as well. It seems the SNGR method or its equivalent can be a promising approach for a broadband component prediction but is used mostly for jet flow noise and lacks experience in fans and pumps. Under a set of assumptions the strick decomposition is made in AVM that includes decomposition of boundary conditions using acoustic complex impedance. This enables the definition of the source of noise and the control optimization of the design.
Conclusions

- Decomposition methods are not yet widely developed in pump pressure pulsation prediction except AVM (tonal noise only).
- In fan noise predictions mostly Lighthill's analogy is used where the best results are reached for tonal noise prediction by application of Kirchoff and BEM integration methods for unsteady CFD data.
- For broadband noise CAA results can be considered qualitative although there is validation showing that with increasing mesh up to 8-16 million nodes LES+Lighthill's variation analogy (BEM) improves the prediction accuracy.
- Using LES increases computational time to a few weeks for each case that is inappropriate for optimization tasks

Michael Dittrich – Low-noise design of complex machines using specific software

Low noise design of machinery, equipment and vehicles implies the incorporation of noise control principles into new or modified product design. As machinery acoustics covers a wide range of metrics, requirements, physical generation and transmission mechanisms, noise control measures and corresponding analysis techniques, there is a need to structure this activity in a systematic manner. This is particularly the case for complex machines which include multiple sound sources, transmission paths and sound radiators. Examples are combustion engine powered construction machines with air cooling and hydraulics, vehicle interior noise with rolling noise, powertrain noise and HVAC noise or power tools with transmission noise, aerodynamic noise and tool/workpiece noise.

Questions to be addressed for the designer generally include the following.

- What resources, such as time, analysis tools and expertise are available to analyse the problem? This will often determine the effort required.
- What is the noise indicator and the required noise reduction?
- This tends to imply the extent of design modifications.
- What is the relevant frequency range and what are the time and spectral characteristics? This will determine the focus of noise control effort, and often depends on the noise indicator.
- Which noise control measures can be considered? After identifying candidate noise control measures it will depend on the design stage as to which ones are allowable within other design constraints such as cost, efficiency, safety and others.

- What is the best combination of measures? Often, a combination of noise control measures is required to achieve the required noise levels.

Today, a wide range of tools are available for measurement and prediction of machinery noise including numerical methods such as FEM, BEM and SEA. Noise measurement and diagnostics are commonly used to characterize the noise situation. Many literature sources can be found on control of various types of noise sources. All these tools can help fullfil the noise target. But a systematic approach can help streamline this process. Recommended practice for low noise design of machinery is described in ISO TR 11688 parts 1 and 2 [1]. In the nineties, the European project EQUIP [2] was undertaken to further develop a methodology and supporting tools for this approach. A map was made of the low noise design process using the so-called SADT technique [3]. Two key elements emerged from this exercise: design rules for low noise design and noise path modelling. These have been implemented in a software package called EQUIP+ [4].

Design rules are especially useful in the early design stages when selecting driveline type and working process, but also when identifying 'Acoustic mistakes' such as structure-borne path flanking or natural frequency excitation. There are general design rules and more component specific ones, for example:

- General rule: up to a limit, improving of alignment or balance in rotating machines will tend to reduce noise from structure-borne sources.
- Component specific rules for fans: operating at best fan efficiency wil minimise the noise emission; larger diameter fans at lower speeds will tend to be quieter.
- For many power components, there is often a quieter type, for example screw compressors vs. piston compressors, belt drives vs. gear drives, electric motors vs. combustion engines. However noise will seldom be the lead requirement.

Basic formulas for sound power, spectral shape or insertion loss as a function of parameters such as speed, load dependence, materials, mass and stiffness and others can point in the right direction and indicate the order of magnitude of particular modifications. Especially insertion loss formulas for the various types of acoustic device are of use, such as enclosures, elastic mounts, damping devices, shunt mass or silencers.

The approach for noise path modelling implemented in EQUIP+ is component-based, which means that only the acoustically relevant components are included in a model, together with noise generation mechanisms, a receiver and airborne, structure-borne or liquid-borne links between them. Such a model is firstly created visually to represent the noise situation for a given machine, and may be based on previous knowledge or on measurements. Noise control measures can already be identified from rules for each component type and the links present. They are generally of the following type:

- Eliminate unnecessary noise generation due to unbalance, misalignment, friction, rattle, unintended turbulence or vortices, or other sources;
- change a design parameter (e.g. structural damping or fan diameter);
- change an operational parameter (e.g. engine speed or loading);
- omit, add or replace component (e.g. belt drive instead of gear transmission);
- change a connection (link) or a disconnect a component (elimination of flanking paths including acoustical leaks);
- add an acoustic device (e.g. damper, enclosure, silencer, elastic mounts).

The following step is to quantify the noise path model so as to allow parametric calculations on the above mentioned noise control measures. Finally, the best combination of noise control measures has to be determined using such a model. The calculation model is typically in the one-third octave domain and includes contributions from the most important sound paths and the effects of several operational and design parameters.

For complex machines, measurement of the basic noise characteristics will often be the first step to identify main sources. Subsequently, a noise path model can be developed which allows to identify relevant design rules, and if a calculation model is built, most effective combinations of noise control measures can be determined.
A wide variety of tools for low noise design of complex machines are available today. A systematic approach using low noise design rules and noise path modelling provides a means of simplifying and speeding up the process.

References

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4. EQUIP+ User Manual, TNO Delft, 2009.

Mark Bastasch – Design of wind turbines and farms

Noise Generating Mechanisms

Wind turbine noise is produced by two sources—aerodynamic and mechanical. The aerodynamic noise level is generally the dominant noise and is proportional to tip speed to the 5th power. However, tip vortex noise is not usually significant. Mechanical noise sources include the gearbox, generator, yaw drives, and cooling fans. Many standard noise control measures may be used to minimize this noise. Typical noise control solutions such as enclosures or silencers can not be used to control the aerodynamic noise. Thus, the aerodynamic noise typically remains the most dominant source.

Relative Importance of Noise and Drivers for Noise Control

Noise is recognized as an important factor in the development and deployment of Wind Turbines. The IEC 61400-11 standard allows for the comparison of sound power levels between models. The market place is increasingly competitive and every decibel increase in turbine sound power level results in greater setbacks to noise sensitive applications leading to fewer turbines or reduced project size for louder turbines.

Wind Turbine Noise Research

Research on wind turbine noise has been carried out by both public and private organizations with the emphasis on aerodynamic noise. These research groups are international and include:

- Sirocco: Silent Rotors by Acoustic Optimization
- European Commission
- Energy Research Centre of the Netherlands (ECN)
- National Aerospace Laboratory NLR, The Netherlands
- University of Stuttgart, Germany
- Gamesa Eolica
- GE Wind Energy
- Risø DTU - National Laboratory for Sustainable Energy, Technical University of Denmark
- DELTA (Denmark)
- National Renewable Energy Laboratory (USA)
- University of Salford (UK), Halmstad & Gothenburg (Sweden)

Wind Turbine Test Facilities and Acoustic Tools to Characterize Sound

There are various test facilities located throughout the world including the National Renewable Energy Laboratory (USA), Netherlands, and Denmark. Acoustical tools utilized include acoustic arrays, parabolic microphones, and IEC 61400-11 methods (narrow and 1/3-octave analysis). Acoustic airfoil computational design tools used include Xfoil, AIRFOILOPT (Risø DTU), and SILANT. Acoustic wind tunnel testing is also performed.

Outdoor Sound Emissions

The sound power level of turbines is determined by IEC 61400-11: Wind Turbine Generator Systems Part 11: Acoustic noise measurement techniques. This method uses a microphone mounted on ground boards located at hub height + ½ rotor diameter from the turbine. Concurrent sound and wind speed measurements are collected with and without the wind turbine operating over a specified range of wind speeds. From these sound pressure level measurements, the sound power levels are calculated (one-third octave bands from 20 Hz to 10 kHz to be incorporated in upcoming update of the standard). The standard will be updated to reflect a reference wind speed height of hub height rather than 10 meters because of the confusion and complications in understanding wind shear and the 10 meter height reference.

Sound Quality

While subjective criteria are not part of the IEC 61400-11 methodology the standard assesses tonality using a narrow band analysis and also provides one-third octave band results. Amplitude modulation (swishing or whooshing sound) has been noted by some. A recent UK study (Morehouse 2007) found modulation was an issue at only four out of 130 wind farms studied, and remains an issue at only one. A modulation quantification method was suggested by Lee et al. at the International Wind Turbine Noise Conference (2009) in Aalborg, Denmark.

Wind Farm Sound Planning

When considering the development of a wind farm, the following tasks are often completed:

- Identification of all noise sensitive areas (residences, schools, hospitals, etc.)
- Identification of setback requirements (roads, property lines, residences, protected areas)
- Development of constraint map, wind resource map, and initial turbine layout
- Obtain sound power level data for proposed turbines used to develop acoustical model
- Iterative refinement of turbine layout based on acoustical and other constraints.

Non-acoustic factors may be as important as acoustic factors and community acceptance likely requires ongoing community involvement. Good public relations and outreach are imperative to create a positive attitude toward the project. Ensuring community understanding of the benefits does as much to foster this attitude as does coordination with the community to avoid conflicts.

Wind Farm Sound Management

If complaints are received, it is important to acknowledge and respond in a timely manner. These may indicate a malfunction or maintenance need. Wind turbine control strategies may also be developed to reduce acoustic emissions.

Wind Farm Sound Measurements

The IEC 61400-11 ground board is not practical for long term measurements as it is susceptible to damage and the pressure-doubling effect of mounting the microphone on a solid surface is confusing to the public. To reduce the effects of wind-induced noise, it is recommended to use oversize or secondary windscreens and to collect and correlate with local (ground level) and turbine (hub height) wind speeds. Potential needs in this area include the development of "certified" equipment or standardization of windscreens and development of wind-farm-specific measurement protocol.

Discussion

CFD

Question: What is the typical time to obtain non-steady computational fluid dynamics (CFD) data?

Answer: It depends on the objective. If the objective is just airflow, it will be a matter of days to a week. If we do acoustics, we can be running simulations for months.

Question: What is the main sound tunnel noise source for the lawn mower shown?

Answer: The blade can be the dominant source for some machines; and in other cases it can be the engine.

Comment: In a following presentation there will be a demonstration of a similar type of modeling, called noise prototyping, where you can hear the noise.

Low-noise Mechanical Components

Question: There was an interesting comment made about designing non-linearity into the system from the outset. Please expand on that?

Answer: One example is when there is a backlash between the gears. People try to control that backlash, but it is important to make sure that the parts are meshing together or the lubrication is there. Rather than fixing the problem there, we try to fix the problem elsewhere in the system. And we must make sure the two sub-systems are physically coupled. Then somewhere in the system you try to introduce a discontinuously non-linear sub-system. For manual transmissions it can be done very easily by having a dual, triple, or four-stage clutch damper. When a vehicle manufacturer needs this, it is sent it to a vendor to try different (multi-rate) springs. Another way to do this is by inserting significant dry friction, and we have seen through our detailed theory and experiments that non-linear friction solves the problem and viscous damping does not. Thus this is an area which is completely barren. We tend to treat non-linear elements as if they are "evil" in terms of theory and in terms of experiments. In fact we make sure in all experiments that non-linear elements are somehow linearized to take advantage of the principle of superposition. In real life, designers use non-linear components (and nature is non-linear), so why can't we take those concepts and use them to our advantage. We need to be careful that we use non-linear elements to resolve the problem and not amplify motions and noise.

Question: It's a great idea, but the analysis of it is hugely difficult, isn't it?

Answer: The analysis is indeed complicated. Rather than doing the truly non-linear analysis, I would do an analysis of the linearized system as a first cut from a design viewpoint. Once I've chosen a reasonable design then I do more a detailed non-linear analysis. An optimization based purely on non-linear system analyses is virtually impossible. Start with a linear system, gain some insight. and see exactly what needs to be done. Try to optimize based on the localized non-linear sub-system, not necessarily on a global basis. So the question comes up again: What is the role of dynamic non-linear interactions between sub-systems? The simplest example I give to my students is: If one non-linear sub-system is "King Kong," you need a "Godzilla" to kill him. But be careful; what if they join forces? Then there will be double the destruction! We have actually seen experiments where this happens. You need to control (what I call) an intentional non-linear system.

Question: If you address this non-linearity problem issue, will it be connected to prediction accuracy?

Answer: In many of the noise problems there are often two issues. One is: Are you attacking the mean or are you attacking the standard deviation? Generally what happens is mean ± standard deviation is not a symmetric problem. As an example, consider that the mean is very high; sometimes standard deviation is then very low. I can design a lousy (noisy) machine very consistently all the time. On the other hand if the machine is relatively quiet from a design viewpoint, standard deviation is tremendous. So what we try to do with this kind of problem is to examine it in terms of both mean as well as standard deviation. That's the key. Non-linear system design is far trickier. Control system people have already experienced this issue. They try to minimize the non-linear effect in order to solve the problem. Sometimes that can be implemented. I know many examples. We have found it to be useful, but what are the generic principles? I think this is where more research is needed. It is seen in active or smart materials; one of the advantages is that they are inherently non-linear. They are amplitude-sensitive, their properties change with frequency. For example, at one frequency strong damping is wanted then at another frequency you want even more damping. To be amplitude sensitive, the damper has to be a non-linear damper. There's no way in the world you're going to get a linear damper. A number of people have suggested particle dampers, sand dampers, and so on. They are inherently non-linear. Sand is one of the best for damping. I've had people from India and China call me, because sand is a good damper, and offer to ship me some. These are rather complicated issues. They are related to sources as well as paths and require long-term work. You cannot get answers overnight.

Low-noise Machinery and Equipment

Comment: The questions were addressed to the panelists before the finalization of their presentation. Those questions were more addressed to manufacturers of machines than to members of institutions working on the reduction of noise. The number of participants coming from industry and specifically manufacturers of machines has been limited in this meeting because of the economic situation. The first four questions were linked to the reason why manufacturers get involved in noise reduction. We know that the answer depends on the type of machine.

Question: Is there an increase in the importance of low-noise criteria for a machine or is the importance diminishing now?

Answer: Let me give you one perspective. I've had discussions with company executives, the people who dictate the vehicle designs, and they say that the suggestions we have for noise control do cost money. If there are minimum-cost noise control suggestions, they are willing to listen. That's true of many industries which question the solutions we come up with. We have to minimize the system complexities—especially the band-aid solutions that we attach during production. We have to impress on them that they could save money through proper design. They should put more resources into producing low-noise sources at the design stage. I don't have an answer; this is just a management perspective.

Comment: There needs to be a change in values. If you offered a car company a solution to make the car safer, they'd throw money at you.

Comment: Nobody will throw money at you for anything. They are willing to listen to you, but you have to prove it. It has to work, not only for one time in the lab, but it has to work in production. I think that's the key. Everything is on a volume basis—proving it for one vehicle or one component doesn't cut it—it has to be across the board.

Comment: A common question raised by management when you propose a noise control solution is: How many dB per dollar? What's going to be the incremental cost of putting in grommets to isolate a component or doing something else? There's going to be the question: What's the relative benefit? That's difficult to answer.

Comment: As a contract research organization I can add that when manufacturers have a problem, a noise problem, they come to you and offer you money to consult.

Comment: Often the question asked: What is the consumer willing to pay for the product noise differentiation? The consultant is contacted when there's negative impact on the bottom line because your product is noisy. But if you are positive—let's say your product noise is the same as the last generation, but the functionality, performance, or energy reduction improves and the product acoustics stays the same—it will not impact the bottom line. So it's not only about noise, but how much the noise impacts profits and in what situation the noise problem becomes a factor. Again, the question comes down to how much manufacturers are profiting from the consumer who is willing to pay for lower or better product noise. If you consider the automobile or home appliance industry, there are product models where acoustic/quiet is one of the key attributes that define a higher-class product. In those situations, consumers are willing to pay for acoustics to some degree. But for many other consumer products, acoustic/quiet is not one of the key product attributes. In those cases, acoustics/quiet becomes important only when there are negative rather than positive results (return issues, perception of poor quality, etc.).

Low-noise Product Requirements

Question: Where does the requirement for a low-noise product come from (regulations, management, purchasers, end-users, or other manufacturers integrating the product)?

Answer: First of all there is the usage. For example, the device in a home-type setting, in a living room, has to be quiet enough to be accepted by end users. Others are the competition between manufacturers and product returns/service calls. Another driver, especially in Europe, are voluntary eco-labels and purchase specifications. Those are important drivers in the IT industry in terms of acoustics.

Answer: Refrigerant compressor manufacturers sell to technically-knowledgeable customers who integrate the compressors into the product systems. So for compressor manufacturers, the incentive to produce quiet compressors is almost entirely driven by the integrating manufacturers. There's an interesting balance that the integrating manufacturer performs. He typically has some noise-control expertise on staff. He would like to have a quiet compressor, but he doesn't want to pay for it. He makes a judgment as to whether it's better to pressure the compressor manufacturer to quiet the noise or just quiet it himself. They have methods such as enclosures, blankets, and other methods that get the noise down to acceptable levels.

Answer: There is yet another motivator for some products which is the warranty cost. Do you have a product with a warranty? Either noise or some other malfunction can be the problem. If you take it back to the dealer, there may be a substantial cost. Unusual noise problems could come under the warranty umbrella. That may be very costly in some cases.

Comment: In many consumer products nowadays, the margin or net profit from a product is very small; so if the noise indicates to the consumer there is some malfunction or a low-quality product was purchased, the consumer may return it. They're earning, say 1 USD of margin on the whole product, but their warranty return cost is 100 USD. So product-related noise issues that may trigger consumer returns are a big headache because of cost; and that's where a lot of attention and research is devoted. But it's after the fact. Often you want to discover the problem much earlier to avoid the cost. You are constrained by integrated parts. Let's say if it's the noise from a little motor in a printer, you want to constrain it much earlier preventing any product return occurring because of the warranty on the product.

Comment: This is the kind of issue which never gets written up in any of the technical papers. Sometimes companies actually do analysis as a motivating factor for low-noise products.

Product Integration and Product Returns

Comment: At Hewlett Packard we integrate components into a system. We buy hard drives, for example; and we have requirements for our vendors. If there is an issue with hard drive noise or a failure, then the hard drive or faulty component goes back to the vendor to determine the root cause of the problem. Where is the failure? But the warranty cost, as was pointed out, is very high even if there's nothing wrong with the hard drive or component. Sometimes people will log in field returned systems, bring them down to the lab and ask if they meet the spec or not. But, it really doesn't matter because, if the customer is not happy, the damage has already been done.

Comment: I'm not sure about the paper aspect of this. There is enough information internal to a company or shared between the supplier and the manufacturer. They're usually defined by specs. The specs are very detailed.

Comment: Another problem that sometimes comes up is that a product is returned because the customer is not happy, but the people fielding the return don't get very good information from the customer. They may say it is a noise problem, but they don't say whether they are bothered by a high-frequency sound or what. Is it a whining noise or is it intermittent? They don't get very good information, so it's important to try to understand what they were complaining about. There are many aspects to the end user interface with a product— noise is one of the factors.

Quiet Product Cost

Comment: When you discuss these problems with top managers, you said you must not add weight, you must not add costs. Does this mean that you don't get the job to fix the problem? To quote a distinguished colleague: "There is no law of nature that says that a quiet product is more expensive than a loud one." Have you good examples?

Answer: The first example is whenever I talk to management, because we are in the academic business, I attempt to get money for research, not to fix problems. I've learned never to promise an answer because innovative answers sometimes are not attractive answers. We had a workshop when we started our NSF Smart Vehicle Concepts Center, and we discussed a number of different actuators. Somebody from industry got up and said that they had a roomful of these actuators—very innovative—but most of them are noisy. They're never going to make it to the market. So you can have a number of innovative products, but some of them will never make it because of noise or other considerations. Whenever I talk to management, I tell them that this is a long-term process. You need to aim for design, not necessarily band-aids. A band-aid will always cost you more money even though it seems like only 2 USD here, 0.5 USD there, it becomes significant money. So a research project is cheaper compared to the band-aids if it leads to a solution. Not all projects will lead to a solution. Sometimes our answer is to do more research.

Comment: Regarding the noise of rotating machinery, a simple, low-noise solution may be contradictory to the power requirements and the efficiency of the machine. Solutions for low-noise design may be needed when manufacturers increase, for example, the power and efficiency of the machine such as the cooling capacity of fans. In that case inevitably it increases the noise; but if we try to reduce the noise, the efficiency or the power may be degraded. It may be costly to find a good solution.

Question: How are relations managed between the manufacturers of noise-generating components and the manufacturers of the complex machines integrating them?

Answer: This question is highly political, and the answer depends on cost. Leads to finger pointing—it's your fault; you pay for it. This is a most difficult question.

Noise Research

Question: The next question is linked to the way a company—small or medium sized—copes with noise research. My own experience is that, with the exception of the automotive industry and other large companies like Caterpillar, there is only a limited ability within the company to work on noise issues. This explains why, depending on the situation, the problem may be handled either inside the company or outside. The question is related to the cost of the test facility and equipment. How many people are involved in a company to cope with noise issues?

Answer: I have learned while supporting product development in the U.S. that, as far as HVAC is concerned, product managers are very optimistic. They believe from the point of concept through paper design that their product is inherently quiet, without any need for consideration of sound and vibration prevention. It's very difficult to convince them that they need to do certain things before they actually build a product, because this goes against their optimistic viewpoint. When the hardware arrives and the sound and/or vibration levels exceed expectation, they believe something is wrong with the hardware, and they ask that the "problem" be fixed. If you reach into your sound and vibration toolbox and apply a cure (a damping treatment for example), you have effectively shot yourself in the foot. The product manager will continue to believe that the design was good, but the hardware was not built as intended. Sound and vibration prevention early in the design cycle is still not considered. I had a profound moment with a roomful of executive managers shortly after everyone listened to a rather loud compressor. I had been frustrated; they were frustrated when I finally posed the problem in a different way. I told them that this compressor is not too loud. It's making exactly the sound that it was designed to make. If you want it to make lower sound, you need it to design it to be lower. That's the kind of thing that I think needs to be done more often.

Comment: This is a good example of a medium-sized company which manufactures a product which is a critical component when it is integrated in larger products. Even then there is only one person to cope with the problem. That's very common.

Comment: The key word here is that managers think in terms of noise—somehow fix it. In other attributes they will ask you to study it and analyze it. Somehow you can find a magic fix, find something to make the problem goes away. Where there's an energy issue, we'll study and find alternate solutions. Whereas noise is kind of an afterthought, now we have it, though we didn't expect it, but it happens almost 100 percent of the time. It would be a pessimistic outcome even though they are optimistic designs.

Comment: In these situations the product managers believe the acoustician has a sort of magic wand. This is not possible in many cases.

Comment: Intel has a research group called Intel Labs that is the central research facility at Intel. We have a handful of acoustical engineers—two in Oregon and two in Guadalajara, Mexico. We study the source, the transmission paths, and the receiver aspects in our research groups. Then we work with our business groups, and they then work with OEMs and HV or vendors on the technologies.

Comment: IT technology is much further advanced than most other industries because of the past and current interest in the field. The problem of noise in this type of machine demands specialized effort. This is not generally the case. For example, we are in a room where there is supposedly a silent HVAC system, but this is not really the case. Nonetheless, it is a much better place compared to places where people work in industry.

Test Facilities and Tools

Question: How much is a company able to devote to test facilities?

Answer: Our research facility in Mexico is pretty well equipped. We also have environmental labs that do the standards testing for other business groups. They not only test acoustics, but also do other types of environmental testing.

Comment: The long-term prospects for test facilities in some companies do not look good. The last couple of decades of severe cost cutting and "lean" operation have seen little investment in test facility construction and test capability development. These companies end up doing the most with what they have in terms of test facilities. Often the engineer leans on experience acquired over years of laboratory or field testing to compensate for inadequate test environments. Investment is also lacking in the training of younger engineers in sound and vibration testing techniques.

Comment: In terms of tools and software, I've had some bad experiences. Management may sometimes be approached by vendors with "magic" software to reduce the noise of their products. The vendor claims this new tool will solve for the company that which the classical engineer has not been able to solve. I have had experiences where the management of small companies has been persuaded to buy sophisticated software or equipment to solve a noise problem. What finally happened? After six months or one year, the noise problem was not solved; so they came back to us to solve the problem leaving us only two months in which to do so. A lot of money was wasted some years ago in this way by companies in France.

SESSION 2: Low-noise Products

Panelists

- **Goran Pavic,** INSA Lyon, France (presented by Jean Tourret)
  Noise synthesis using a hybrid substructuring approach
- **Chuck Hayden,** NIOSH, U.S.A.
  Noise control by design of air compressors and pneumatic hand tools
- **Bob Anderson,** Consultant, U.S.A.
  Noise reduction at source in manufacturing plants and workshops
- **Bill Lang,** Noise Control Foundation, U.S.A.
  Low-noise household appliances

- **Tom Reinhart,** Southwest Research Institute, U.S.A.
  Low-noise, off-road recreational vehicles
- **Egons Dunens,** Hewlett Packard, U.S.A
  Noise reduction at the source in offices

Presentations

Goran Pavic – Noise synthesis using a hybrid substructuring approach

Position in Industry

A low-noise product is difficult to conceive at the design stage because of the following:

- permanent improvement of industrial products needed
- quick prediction of noise at the design office level required
- component suppliers and product assemblers lack coordination
- profound shortage of information on noise of components
- noise regulations exist for finalized products, not for components
- no design data on the link between vibration, pulsation and noise
- software for noise prediction difficult to use, requires extra skill
- software lacks reliable handling of noise sources.

Typical Industrial Product

A product such as a washing machine has three “acoustical” elements: sources, connections, and frame—in the same way as a violin

Classical Protoyping for Noise

This is a multifaceted work where tests are done on an assembled prototype and where different noise sources are compared to each other. To reduce noise there may be modifications to the connections and mainframe to increase stiffness, an adjustment of the component’s position within the frame, or the use of absorptive material and damping layers.

The classical output is the noise spectrum at a reference position and/or the total power radiated, but it can also be a subjective noise assessment by made by listening. Virtual prototyping should carry out the same phases but on a computer. But vital information and data must be taken from the real world!

Sub-Structuring

This is the backbone of virtual acoustic prototyping where the principle is to break the unit down into its components and analyze each component separately. Then the coupling forces at interfaces must be identified and the global behavior reconstructed.

Virtual Noise Prototyping Using Noise Synthesis Technology (NST)
The objective of NST is to predict the impact of alternative solutions and modifications of an industrial product on its global noise using an industrially-feasible technology. This may be applied to any industrial object which can be decomposed into an assembly of noise sources and noise transfer paths (air-borne, structure-borne, fluid-borne). NST shifts from the scale of fine detail to the scale of entire mechanical components. At the component level, computing is usually replaced by measurement evolving gradually toward either empirical, scaling-law, or simplified analytical models. The initial development of NST technology was done within the EC project GRD1-10785 Noise Abatement using Concurrent Component Optimisation.

Summary of NST Approach

The NST approach is to make things as simple as possible, but not too simple.

- The source is characterized in a deterministic way by direct measurements (Component Source Strength CSS)
- The connections are characterized by either measurement (e.g. rubber mounts) or computation (e.g. couplings) (Connection Transfer Function CTF)
- The frame is characterised in a statistically averaged sense in order to account for its sensibility to perturbations (Frame Conductivity Function FCF)

Comprehensive Source Characterization

All effective noise-generation mechanisms have to be considered. The three typical mechanisms are air-borne (radiation from housing), structure-borne (feet, pipes, connectors), and fluid-borne (gas/fluid pulsations).

Source Characteristics (CSS)

NST requires adapted methods and dedicated test rigs. Standardized test methods are generally unsuitable for an NST approach! Examples are the characterization of structure-borne noise of an electrical motor using the Blocked-Force method and the characterisation of air, structure-and fluid-borne noise of a small hermetical piston compressor using the 6-accelerometer and 3-pressure sensor methods respectively.

Characterization of Connections (CTF)

Either measurement or computation is possible, but the characterisation of certain types of coupling elements, like rubber mounts, will have to be done experimentally. In opposition, metallic couplings of well-defined shape and material properties are most conveniently characterized by computation, e.g. using FEM.

Obtaining Frame Conductivity Function (FCF)

The characterisation of frame is a technology uncertainty problem. Nominally identical structures can give different acoustical signatures. Small variations in the machining, assembling, and installation will smear the frequency properties of different (flexible) frames. Frequency smoothing techniques are used to get transfer functions of transmission paths.

Noise Synthesizer (NS)

NS is the tool for virtual prototyping. Noise prediction is done with the help of multi-task software to which is supplied input data obtained on both the sources and the frame! It uses a particular noise synthesis scheme defined by the user. The functions of NS are:

- select the least noisy component(s) relative to the given frame
- rank different noise transmission paths
- predict product noise
- get an appreciation of product noise quality
- assist in the analysis of noise reduction

The basic output of NS is to produce a noise spectrum of the assembled product and to synthesize product noise for audio reproduction.

Noise Synthesis

NS is a chain of complementary operations. Synthesis of a noise waveform may be done from a RMS noise spectrum in case of random or periodic signals or by convolution of impulse response obtained from FRF Transform.

Example of a Walk-Behind Lawnmower

Noise-generation mechanisms can be split into engine noise (radiated directly by exhaust, and by its structure, or indirectly by vibrations induced in the deck) and blade noise (radiated in the deck outlet, through the leakages between deck and grass, and inducing vibrations in the deck).

Example: Noise Synthesis

The approach for a ride-on lawnmower includes:

- blade characterized as a noise source on a specialised test bench
- deck characterized by its insertion loss (loudspeaker excitation)
- engine characterized by partial sound powers emitted (6 faces)
- engine structure borne characterized by engine/chassis mobilities
- exhaust characterized by near field measurement using reciprocity
- free-field propagation away from the mower assumed.

Summary

The main features of NST technology by hybrid sub-structuring are that it:

- is suitable for a large variety of products
- offers increased independence to designers
- enables noise data exchange between suppliers and assembler
- is product-dependent
- provides improved understanding of noise generation and transmission
- enables noise prediction & listening
- allows assessment of noise reduction by design

The main benefit of NST technology is virtual prototyping.

Chuck Hayden – Noise control by design of air compressors and pneumatic hand tools

The focus for controlling noise emissions from air compressors relies heavily on barriers and enclosures for blocking noise pathways. Control of noise emissions for pneumatic hand tools is more generally focused on muffling or redirecting exhaust air from the device itself. While both types of products are known to emit high levels of noise, manufacturers of air compressors can more easily recommend the use of administrative controls such as locating the compressor in areas isolated from personnel. Conversely, manufacturers of pneumatic hand tools can be certain their product will be used in close proximity to the tool operator or other personnel. Regulatory emphasis on noise emissions from both products is typically driven by environmental considerations and not necessarily to reduce noise levels likely to contribute to an operator's noise induced hearing loss.

Manufacturers balance the target market (high-, medium-, or low-end), energy efficiency, and reliability into their product design. Over the last few years the increasing importance of environmental design, with noise emissions being of particular concern, is a strong consideration. Additionally, pneumatic hand tool manufacturers must consider ergonomic issues such as vibration isolation and hand grip design into their product. Some design constraints related to noise control of hand tool designs incorporate the muffler into the hand grip while ensuring the grip is not so wide in circumference that gripping becomes difficult or uncomfortable. A muffler may reduce noise emissions but at the expense of a significant reduction in the power of the tool. The additional weight of the mufflers must also be considered as part of the overall ergonomic evaluation. Added costs associated with noise control designs are difficult to quantify, but using compressors enclosed in canopies as a reference, the extra cost is typically 5 percent. The cost for noise controls on hand tools may be significantly higher as the complexity is increased and the overall product cost is lower.

In 1969 the manufacturers' trade associations in the US and Europe developed the CAGI-PNEUROP Test Code for the Measurement of Sound from Pneumatic Equipment (ANSI S5.1 1971) to enable air tools to be measured and compared. More recently manufacturers selling to the European Economic Area have been obligated to comply with the Machinery Directive (MD) requiring machinery to be designed so the risks from noise emissions are reduced to the lowest level while taking into account technical feasibility. Also the noise emission values must be stated in the manual accompanying each machine. More recently, Directive 2003/10/EC has imposed a responsibility on employers in the EU to manage and control the noise exposure of their employees. This has resulted in power tool purchasing policies specifying requirements for noise emissions. For compressors, products for outdoor use are regulated by specific legislation: Outdoor Noise Directive 2006/14/EC (Europe) and the Noise Control Act 1974 (USA). The products for industrial use indoors are governed by the regulation of noise exposures in the work place. However, noise exposures in industries such as construction, a large component of the pneumatic hand tool market, find little enforcement in the U.S. Never the less, environmental regulations continue to be strengthened regarding general noise levels. This is particularly to be found in municipal regulation and enforcement such as the recent New York City Department of Environmental Protection (NYC DEP) noise regulation. Within the NYC DEP regulation is a focus on construction sites within the city and a vendor list of recommended quiet equipment. Because of this, manufacturer's have a strong economic motivator to produce and market quiet equipment within the NYC construction market. This trend can be expected to expand across the country as communities become more proactive against the adverse effects of high noise levels in their cities and neighborhoods.

Industry influence on the development of noise level test standards for pneumatic hand tools has resulted in the inclusion of statements such as "… declared values are not adequate for use in risk assessments…" in existing test standards. This includes those of ANSI, ISO, and EN. The statement which diminishes the need for gathering such data is primarily for use in assessing whether a hazardous environment exists or for informational purposes in choosing and using appropriate personnel protection equipment. Revision or development of product noise level emission standards should first consider why the standard is needed in the first place—Is the test standard drafted for product development, operational diagnostics, or risk assessment? The need for relevant standards to assess the hearing hazard to operators of machinery and tools is significant and should be addressed. If not, hearing loss among certain groups of users such as construction workers will continue to be high.

The hand tool industry tends to design their noise control components, mainly mufflers, in-house. In the compressor industry, most co-engineering occurs only between suppliers of noise-control components for the integrated package. That is components not specifically designed for noise control are not co-engineered for quiet with respective manufacturers. The industry states that all product design personnel are involved in noise control as an integral part of product development. Noise control design is such that without design engineers specifically trained in acoustics and noise control, the opportunity for a significant noise reduction is diminished. Industry should do more to seek technical expertise with formal training and experience in engineering noise control and acoustics. Sound level testing for hand tools is accomplished in accordance with ISO 3744 and test rigs, as required, in accordance with ISO 15744. For compressors, a number of environments are used depending on whether the compressor is portable (open-air, noise-scanning yard) or stationary (test cells suitable for near field noise scans) with special test rigs used occasionally (analysis silencers, evaluation rotor-dynamics, rig/equipment allowing for modal analysis).

For air compressors and pneumatic hand tools, sound quality is typically not a consideration. As the products' noise emissions are reduced over time, this area of research could become more important, particularly with hand tools and the tool operator's desire for auditory feedback during the tool's use.

Recommendations

The revision of existing noise level test standards is necessary to be applicable in noise hazard risk assessment. Future standards should be web-based, written concisely, and include HTML links to specific issues now described in full in written standards. Future standards drafts and revisions should include spreadsheet tools to streamline what is now a heavy dependence on complex written equations. Existing noise level test standards are inadequate in providing a noise level measurement relevant to the operation of the machinery or equipment; this is particularly true when the product is hand-held.

Bob Anderson – Noise reduction at source in manufacturing plants and workshops

(Prepared by Noise Control Foundation from Bob's presentation)

Fundamental Questions

The following fundamental questions are asked about noise control in industry:

- What is the state of noise control technology for industrial equipment?
- Does the cost of noise control impede implementation of quiet technology?
- What drives the decision to implement control technology?
- What resources are available to those who responsible for integrating noise control technology into equipment?
- How is the control technology evaluated? Are there benchmarks and design goals for sound emission levels?

What Drives Noise Control?

In established heavy manufacturing, large companies are influenced by unions, compliance, and the need to control costs, including medical; Buy-Quiet programs are drivers. In small companies control of cost and compliance are recognized but there are few Buy-Quiet programs. In "green" technology manufacturing for both large and small companies, compliance and medical costs are influencing factors; and Buy-Quiet and retrofit programs are drivers.

Motivating Factors in Buy-Quiet Application

There are several motivating factors in Buy-Quiet applications.

- New equipment whose operation will not appreciably increase noise levels in existing work environment.
- Minimize cost of engineering noise controls.
- Combine with other standards and controls to achieve added benefit for metal-working fluid control and ergonomics.
- Introduce added efficiencies through "re-engineering" and improvement of processes.

Adantages to Adopting Noise Control in New Equipment

The cost for noise control in the design/build stage is less than in retrofit, and controls can be integrated into the design. Controls have less potential penalties to production and maintenance, and the costs of controls are covered under project costs and new capital equipment. Another advantage is the use of supplier knowledge supplements limited in-house process noise control engineering expertise.

Impact of New Technologies and Supplier Relationships

New technologies make possible process automation which includes robotic functions to remove or replace worker, multi-function equipment where the operator becomes the monitor, and positive part control. Collaborative purchaser-supplier relationships make them partners-in-design using the supplier's process design expertise and encourages design initiatives and alternate processes.

Manufacturing processes include machining operations and heavy manufacturing power presses (source components and controls), and assembly welding. Support processes use compressed air systems, hydraulic power units, and hand tools.

For forming operations enclosures are designed to control metal-working fluids, oil mist, smoke, and noise and result in sound emission levels below 90 dB(A). The enclosure also serves as a machine guard. For machining operations enclosures serve multiple functions including guarding and result in sound emission levels, under load, below 80 dB(A).

For transfer presses, enclosure of die areas, drive-train, and de-stacking areas results in sound levels under full production below 85 dB(A).

For metal assembly weld cells replacing pneumatic drives with servo drives reduces noise from spot-weld impacts while extending weld-tip life and saving energy. Worker noise exposures are less than 85 dB(A).

Commercial controls for compressed air noise are available for air jets and pneumatic exhausts, and hydraulic surge suppressors provide noise control for hydraulic power systems.

Noise control is achieved for power tools by replacing pneumatic tools with electric tools and impact wrenches with impulse tools.

Die design activity is typically contracted to competitive design firms who may not consider noise control techniques.

In part and scrap ejection systems the machine supplier is typically not responsible for noise generated by tooling, loading, and material handling. For these systems controls are assumed by the buyer who may not have noise control expertise. In many production equipment installations, the buyer is also responsible for machine mounting and vibration isolation is often not considered as an integral component of the installation.

There are technical issues and supplier issues which present limitations and obstacles to successful noise reduction. The technical issues are manual load and unload, tooling, and material handling. The supplier issues are lack of technical expertise, lack of direction and/or expectations, and misapplication of materials. An example of misapplication of materials is the use of unprotected, open-cell urethane foam in new equipment.

An example of misapplication of process may occur due to the inappropriate location and selection of the paint spray booth. If a vane axial fan is located close to the operator's position, it will negate the positive effect of the spray booth enclosure itself.

Convenience materials include those that are readily available in a shipping operation, for example, quilted blankets. These materials are increasingly used for retro-fit enclosures and are unsuitable because the sound transmission loss they provide is inadequate, and any money saved by their use should be spent on materials with a high transmission loss.

Measuring Noise Controls

B11.TR5-2006 - ANSI Technical Report for Machines: Sound Level Measurement Guidelines specifies methods for measuring, evaluating, and documenting sound pressure levels emitted by a machine production system during normal operation and when running at idle. It is intended to be most compatible with the actual conditions encountered in industry and permits the selection of equipment using 'buy-quiet purchase specifications' or to estimate the effect machinery will have after installation. The location of the microphone is on a measurement envelope that encloses the machine at a distance of one meter from the closest surface of the machine.

Conclusions

- Commercial and process noise controls are available for application in most new equipment installations.
- Cost is a major factor in decisions to implement control technology, especially in retro-fit applications.
- Within the US, the hearing conservation compliance alternative to engineering controls discourages retro-fit activity.
- Within the manufacturing user base there is a lack of noise control awareness and expertise. There is limited knowledge and expertise within the supplier base.

What is needed?

- A standardized noise emission labeling system needs to be developed.
- Strengthen existing measurement criteria by adding provisions for impulsive noise emissions, promoting addressing "machine system," and adding consideration of vibration and shock isolation.
- Enhance supplier and user awareness and expertise through technical training in measurement and control fundamentals.
- Make the case for added value of low-noise product.

Bill Lang – Low-noise household appliances

The Association of Home Appliance Manufacturers (AHAM) classifies household appliances in three categories: 1) major home appliances, 2) portable home appliances, and 3) personal care appliances. In the first category garbage disposal units, dishwashers, room air-conditioners, and clothes washers and dryers are principal sources of noise complaints. In the second category fans, vacuum cleaners, food processors and mixers are most often criticized for their noise. In the third category only hair dryers are of concern as being noisy.

Requirement for a Low-Noise Home Appliance

As hearing is not threatened, the requirement for a low-noise home appliance is principally market-driven by purchasers and end users. In Europe there are eco-labels with noise as a criterion.

Low Noise Performance Versus Other Criteria

Sales price and performance are the dominant criteria for home appliances. Secondary criteria are robustness, energy efficiency, design attractiveness, and low-noise which are all important. The more intrusive its sound, the more important it is to have a low-noise product.

Noise Research and Development

For a typical home-appliance manufacturer, the number of people who are involved in noise research and development is small. Often engineers are "jacks-of-all-trades" working one day on one of a variety of mechanical aspects (e.g. heat transfer) and the next day on product noise.

Extra Manufacturing Cost for Low-Noise Products

The extra cost is easier to estimate for some products (e.g. dishwashers) than for others. Overlapping of model changes may present difficulties in estimating this extra cost; for example to transfer a recent development into a new model (e.g. a quieter way to support a drive motor).

Mechanical Power Source

The noise emitted by the mechanical power source of a typical home appliance is usually a significant contributor to the overall noise emission of the product.

Measurements of Competition

In the home appliance industry measurements of competitive products, including noise emissions, are routinely performed.

Information for the Purchaser

The purchaser of a home appliance needs the means to compare the noise from one product to another and the ability to compare the noise of a product to one with which the purchaser is familiar. Currently the metrics used to describe the noise emissions of home appliances are defined by the IEC.

Subjective Sound Quality

Metrics related to subjective sound quality are used for some home appliances. These include listening panels (such as those used by Consumers Union) that may entail a jury trial rather than a specific metric.

Test Facilities

Because of their size, most household appliances are suitable for measurement in portable and small chambers that are inexpensive compared to those required for larger sources. The test code used by the manufacturer determines the optimum design for these facilities.

Example: Dishwashers Competitive Claims

- "Bosch dishwashers are the quietest in the U.S." (manufacturer's claim)
- "World's quietest dishwasher, Kitchenaid Superba EQ, at 41 dBA per IEC Standards." (manufacturer's claim)

Role of Dishwashers

- Unit frequently installed in open kitchen near a dining or family room.
- Cycle times may exceed one hour.
- Of all home appliances, dishwashers have potential for significant intrusion on family life.

Today's Technology

Top-of-the-line dishwashers are quieter because of:

- Smaller, vibration-isolated, variable-speed motor (3/4 hp reduced to 1/8 hp)
- Two small pumps individually wash and drain
- Solid-molded, single-piece base blocks sound
- Longer cycle time (35 minutes lengthened to 1 hour 20 minutes)
- Hard-food grinder replaced by clean-out filter
- Hot-air blower for drying replaced by heater element or very hot water
- Heavy-weight sound-absorbing blanket covers tub
- Sound-dampening mastic on exterior of tub reduces noise from interior of tub
- Alternating wash zones reduce water sounds by reducing amount of water used at any time

Results: "The New Sound of Silence" (manufacturer's claim)

- Engineering improvements produce "world's quietest dishwasher" at 41 dB(A) per IEC standards.
- Bottom-of-the-line dishwashers without engineering improvements have noise ratings up to 65 dBA.
- 20-25 dBA engineering improvements offer nearly silent operation.
- Comparison with early dishwashers demonstrates considerable progress in noise control technology.

Technology Assessment

- Sales of household appliances are primarily market-driven.
- Availability on current market of many low-noise appliances demonstrates that technology is currently available.
- Market for low-noise appliances depends partially on location of appliance within the home as well as cycle or operating time.
- Demand for low-noise appliances differs by geographical region.
- More uniformity of test codes across industry would facilitate noise comparisons of competitive products.
- Low-noise household appliances generally sell at premium prices.
- Often the 'greener' the product, the quieter the product.

Tom Reinhart – Low-noise, off-road recreational vehicles

Introduction

The types of vehicles considered in this presentation include:

- Snowmobiles
- Jet skis
- Off-road motorcycles (dirt bikes)
- All-Terrain Vehicles (ATVs)
- Micro- and Ultra-light aircraft

Each type of vehicle presents a range of issues and technical challenges. Regulators will want a easy to perform noise test that has high repeatability and which represents the noise in actual use. Efforts to reduce noise may cause reductions in performance, as well as increases in weight and cost. One major factor that comes into consideration for off-road recreational vehicles is owner modifications that intentionally increase noise. This means that enforcement has to be aimed at individual users, not just at the vehicle manufacturers.

In general, buyers of off-road recreational vehicles have very different noise concerns than buyers of, say, automobiles. Many (not all) buyers of off-road vehicles actually want as much noise as possible, or at least a lot more noise than many bystanders can tolerate. These buyers have a strong interest in the image of the vehicle, and noise plays an important role in that image. One could call this the Harley Davidson effect. Sound quality is important to buyers—they don't want just any noise, but they often do want a lot of the kind of noise they enjoy.

Factors that are critical to buyers of off-road vehicles include performance, handling, weight (which has a strong influence on both performance and handling), image (in which noise plays a significant role), reliability, and cost. Secondary factors include durability and energy efficiency. Most of the pressure to reduce noise in these markets comes from regulators, who in turn are responding to the involuntary listeners who go to open spaces in hopes of hearing peace and quiet, but who often are annoyed by off-road vehicle noise.

Existing North American Regulations:

Snowmobiles meet a noise level on an acceleration passby test: SAE J192. The J192 test is used by the industry to develop new machines and to demonstrate compliance with regulations. There is also a simple stationary exhaust noise test designed to find user modified exhaust systems in snowmobiles: SAE J2567. This test is aimed at detecting modified exhaust systems and is used in locations such as national parks to approve individual users for operation within a specified area.

Off-road motorcycles are regulated by the EPA under CFR 40, Part 205, Subparts D and E. These regulations apply to both on-road and off-road motorcycles. The regulations have been in place for about 30 years, but the EPA office that enforces the rules closed in 1982. Manufacturers self-certify. ATVs are not regulated in North America, but manufacturers generally meet the requirements for motorcycles, using the motorcycle test procedure. There is also a stationary exhaust noise test for motorcycles and ATVs, SAE J1287. This procedure is aimed at detecting modified exhaust systems, and is used to limit entry into many sponsored off-road events, as well as into certain parks and other areas. Each individual motorcycle is tested.

Other off-road vehicles such as jet skis or ultra-light aircraft face local regulations or no regulation. Typically these regulations involve complete bans or restricted operating hours in specific locations.

Primary Noise Sources

All off-road vehicles share certain primary noise sources: exhaust, intake, engine radiated noise, and chassis radiated noise. Additional sources for snowmobiles include transmission noise, track / suspension noise, and chain case noise (the power transfer unit between the engine and transmission). Track noise is a particular problem on longer sleds which are designed for deep snow, off trail operation. For jet skis, the additional noise sources are pump noise and water flow / impact noise. The classic noise issue with jet skis is the sudden noise and change in noise caused by bouncing over waves. For off-road motorcycles and ATVs, the additional noise sources are transmission noise, chain drive noise, and tire noise. Ultra-light aircraft noise sources include propeller blade pass and airflow noise.

Progress and Future Potential for Snowmobile Noise:

Snowmobile manufacturers have invested significantly in noise reduction technology. Many of the software tools and processes are similar to those used in the motor vehicle and construction equipment industries. Four stroke cycle engines are becoming more popular in order to comply with exhaust emissions standards. Four stroke engines are generally quieter than the 2 stroke engines they are replacing. More sophisticated intake and exhaust systems have become common. These reduce noise, but increase weight and cost, and decrease performance. Low noise intake and exhaust systems also require more package space, which is at a premium on a snowmobile. Two cycle engines require a tuned exhaust to achieve acceptable engine performance. Making a quiet tuned exhaust is a significant engineering and packaging challenge. Barriers, damping, and absorption materials are used within the constraints of durability, cooling system performance, weight and cost. There is room for improvement in the track noise and in transmission noise. Unfortunately, the entire snowmobile industry relies on one track supplier, so competition does not help improve the breed. There are also trade-offs between traction and noise, as there are with on-highway tires.

Snowmobiles suffer from a high rate of customer modifications, estimated by industry sources at 30% or more. These modifications often include replacing the exhaust system with a much louder system, which can exceed the factory system noise level by over 10 dB. Only frequent enforcement testing in the field will be able to reduce or eliminate this problem.

One big issue faced by snowmobile manufacturers is the variability inherent in the SAE J192 passby noise test. Manufacturers report up to 6 dB variability, depending on the conditions of the snow and of the ground under the snow. This makes it very difficult to have any confidence in engineering tests aimed at optimizing a vehicle for low noise. The industry is working on a revision of J192 in an effort to improve repeatability, but even more improvement may be required. One idea is to do noise tests on an artificial surface which would offer significantly increased repeatability.

Progress and Potential for Motorcycles and ATVs

Like snowmobile manufacturers, motorcycle and ATV manufacturers have invested in automotive style technology for noise reduction. Aftermarket modification is a significant problem, but not as widespread as the nearly 100% modification rate seen for Harley Davidson on-highway motorcycles. The primary reason is cost – dirt bikes and ATVs are relatively inexpensive, but aftermarket exhaust systems are fairly expensive. Aftermarket exhaust systems can increase noise by 10 dB or more. The development and certification noise test procedure used for motorcycles and ATVs is reasonably repeatable, unlike the case with snowmobiles.

The 4-Cycle Noise Issue

Four cycle engines tend to be quieter, but there is an issue with 4-cycle engines: low frequency exhaust noise. The firing frequency of a single cylinder 4 cylinder engine operating at 6,000 RPM is only 50 Hz, while a two cylinder engine at 6,000 RPM fires at 100 Hz. Since all regulated test procedures use A-weighting, this low frequency noise does not need to be very well attenuated. A-weighting reduces the noise measured at 100 Hz by 19 dB, and at 50 Hz by 30 dB. Low frequency noise can carry over long distances, making annoyance at a considerable distance a problem. Perhaps a loudness requirement would be a useful tool for improving 4-cycle engine noise. More work is needed on this issue.

Cultural Issues

There are huge cultural and perception problems involved in the noise of off-road recreational vehicles. The owners tend to regard high noise levels as a good thing (the “sound of power”). High noise levels are even considered a safety factor by some owners: “Loud pipes save lives.” Owners tend to think that louder and more powerful go together. It is even a legitimate question to ask if the sales of these machines would be substantially reduced if the machines were quiet and noise regulations were strictly enforced. Owners often fail to understand how their love of noisy machines leads to upset neighbors and to restrictions on when and where they can operate. Owners who use noise–compliant machines are often punished with bans and restrictions because of the actions of those who run modified machines. The problem is not unlike the issue of “straight stack” exhaust systems in the heavy trucking industry. The actions of the “cowboys” make life harder for the industry, and for other users.

When restrictions due to noise issues come into effect, owners of off-highway vehicles feel like victims. There is a very emotional reaction about the elimination of freedom, similar to the 2nd amendment issues regarding any restrictions on gun ownership. On the other hand, the involuntary listeners can be very forceful in demanding their peace and quiet. Vehicle owners often fail to recognize that operating quieter vehicles is a very acceptable common ground that would satisfy nearly everyone. In the end, a lot of public education and enforcement at the individual owner level is required in order to deal with this issue. There is no point in burdening the industry with more stringent noise regulations at a time when many owners are modifying their machines in such a way that one modified machine makes the noise of 10 factory machines.

Egons Dunens – Noise reduction at the source in offices

Introduction

Thirty years ago typical office machines included typewriters, adding machines, mechanical calculators, mimeographs and overhead projectors in meeting rooms. Today these devices have been largely replaced by information technology (IT) equipment such as personal computers (PCs), printers and multi-function devices (MFDs), and digital projectors. So today I'm going to talk about the progress made in reducing noise from four groups of IT equipment: 1) desktop PCs and notebook PCs, 2) workstations and servers, 3) printers and MFDs, and 4) digital projectors. MFDs can have scan, copy, print and fax modes.

Desktop and Notebook PCs

The main sources of noise in PCs are fans, hard disk drives (HDDs) and optical disk drives (ODDs). Fans generally provide a steady, broadband noise that may contain tones at the blade passage frequency and its harmonics. HDDs have a tone at the rotational frequency that may excite the panels of an enclosure. As a result, a 7200 rpm HDD has a tone at 120 Hz that may radiate quite effectively even though the drive itself is small. Some HDDs also have audible tones at high frequencies. ODDs will also cause the PC enclosure to vibrate especially during spin-up when reading the media directory or while performing sequential reads. A 48X ODD has a rotational speed of about 9700 rpm, so a harmonic series of tones spaced 162 Hz can occur.

The trade-offs for achieving a quiet PC are cost, thermal issues, and energy efficiency. Quieter components, sound absorbtive materials, and exotic heatsinks all cost money. The thermal designer would like to run the fan(s) at a higher speed in order to generate more cooling air for thermal margin. But the noise produced by a fan varies approximately by the fifth power of the fan tip speed. A doubling of the fan speed can result in a 15 dB increase in the noise produced. But keeping the fan at a low speed can result in the processor running hotter, thus increasing the amount of leakage current and reducing the energy efficiency of the unit.

The tools for reducing the noise from PCs include using 1) fan speed control, 2) using quieter components, e.g. fans, hard disk drives with fluid bearings, 3) improving the balance of rotating components, 4) using vibration isolation on fans, HDDs and ODDs, and 5) designing more efficient heatsinks so that less airflow is needed.

The demand for low-noise products comes from customers but is influenced by eco-labels especially in Northern Europe. The acoustic criteria in eco-labels such as Blue Angel and Nordic Swan have found their way into bid specifications. Also customers expect the next generation PC to be as quiet or quieter than the current PC even though the new PC is more powerful.

The basic metric used by the IT industry is the sound power level in bels. The standards used include ISO 7779, ISO 9295, ISO 9296 and the Ecma counterparts ECMA-74, ECMA-108 and ECMA-109. ISO 9296 and ECMA-109 are the acoustic noise declaration standards.

Some PC data is presented from 1991 where the average declared sound power level was about 4.9 bels. The 2004 data showed a reduction to about 4.0 bels to 4.1 bels. The current average declared sound power level of 3.8 bels corresponds approximately to an operator position sound pressure level of 28 dB. This is well below typical low-noise office levels of 35 dB to 37 dB. So quiet office PCs are currently available.

Workstations and Servers

The factors for increasing the noise of workstations include: 1) more powerful and multiple processors than desktop PCs, 2) more HDDs and faster HDDs including some with speeds up to 15 krpm, 3) graphics cards (many with fans), and 4) higher wattage power supplies. Some of the same techniques that are used to quiet desktop PCs also apply to workstations. Additional techniques include: 1) using multiple fans operating at low speeds under fan speed control, 2) using ducting to more efficiently direct the airflow, 3) using liquid cooling, and 4) using graphics cards that have thermal fan speed control.

Servers present additional cooling and noise control challenges because of multiple processors, multiple HDDs, and higher component density particularly in low-height rack-mount units. In addition to the previous noise control techniques, additional ones are using multiple thermal sensors to more accurately monitor the temperature at critical locations and the use of redundant power supplies.

Printers and MFDs

The noise emitted by printers and MFDs has a more transient nature than the noise from PCs. The main noise sources include: 1) the paper transport mechanisms, 2) the print head and positioning mechanism, 3) the scanner, and also 4) fans. The trade-offs for achieving a quiet printer include ones mentioned before: 1) cost, 2) thermals, and 3) energy efficiency. In addition, ease of use or easy access to various parts such as the scanner platform is important to the end user. In addition to L_W and L_p, sound quality metrics are used especially to characterize the transient sounds that can cause annoyance. Besides objective measures, such as loudness, sharpness, and roughness, jury testing is also used to determine acceptable sounding products.

ITI TC6 and Ecma TC26 conducted a survey of printers in 2004. Slide 11 shows the results for monochrome laser printers as a function of pages per minute (ppm) printed. The Blue Angel limit is also on the slide. Most printers were at or below the Blue Angel limit line. Slide 12 adds printer levels from my web survey of recent printers. The newer printers were somewhat quieter than the original sample of printers.

Digital Projectors

Digital projectors are used mainly in meeting rooms as opposed in office areas. A bright light is needed for good image quality on a screen, but also the light coming out of the projector chassis must be minimized in order to not distract the audience. So, the heat from the bulb must be removed while minimizing the openings. In 2001, the declared sound power level L_{WAd} on several projectors was determined to be between 4.8 B and 5.5 B. The corresponding average bystander sound pressure levels L_{pAm} ranged from 35 dB to 42 dB. The data on web specification sheets typically only has L_{pA} data. Current values ranged from 26 dB to 37 dB with a cluster of units in the 30 dB to 32 dB range. Most manufacturers declare dual values to indicate operating modes such standard / bright or standard / economy.

Summary

- IT equipment is commonly used in office environments.
- The equipment has become much quieter over time even though the capabilities and performance have increased.
- Consumers/users should match the desktop PC to the environment in which the PC will be used.
- The location in the office of workstations, servers and printers need may need special attention. This equipment may need to be located in an area away from workers or the equipment may need to be placed behind sound absorbing screens.
- Projectors also should be matched for their intended environment.

Discussion

Defeating Noise Reduction in Workshops

Question: Is it common for operators to defeat noise control hardware/methods such as enclosures if inconvenience is introduced?

Answer: It is common for operators to defeat enclosures because of performance. Sometimes it's because the noise controls are designed without full consideration of the production requirements and to make the job more efficient, because the operator is most concerned about getting the job done and sometimes the noise controls get in the way. Sometimes those controls are defeated. One way that the suppliers and manufacturers have been able to counteract that is to lock the enclosure such that the machine fails to operate when the operator tries to defeat it. It's a constant game of war between the operators finding ways to be most efficient and getting the job done and the compromises that are introduced by the acoustical considerations. Sometimes noise controls can affect the performance of things like pneumatic valves. Some of the devices, mufflers especially that are quite common for pneumatic valve treatment, are removed because the machines will not cycle as efficiently due to compressed air contamination. These are things that are part of routine maintenance that are necessary to implement.

Comment: This is a very common attitude.

Comment: We did a study in a manufacturing company with very noisy equipment. The old-style equipment had noise levels that were in excess of 100 dB continuous noise. Any noise control efforts to quiet that equipment were often defeated because of the problems with maintenance. These were all retrofit. The interesting thing is that this factory was closed and the same equipment was sent to a different factory in a different part of the U.S. It was in Chicago and was relocated to Nebraska. The same equipment was sent to the Nebraska plant, but in the process of doing so the company purchased total enclosures for that equipment. It reduced the noise levels to 45 dB; and any time the enclosures were tampered with or removed, the operators protested. So the operators enforced the noise control work because of the fact that the environment was so different. It was what the operators became used to. In the first environment noise was common; in the second environment noise was unusual.

Comment: I think that you are reminding us of the human factor which is very important.

Focus on Sources

Comment: Encourage the science of acoustics to be focused on sources. This policy can only be achieved with financial support for relevant research. The members of CAETS academies should be encouraged to give more preference in education to the fundamentals instead of the present, widely-promoted building acoustics. These education applications should be focused on noise reduction at the source and general acoustics.

Comment: There are two responses to this comment. The first one is research funding on source noise control. The second one is developing a subculture for the science of noise control. Whenever there is a noise or other new problem, management associates that with malfunction; something has to be fixed. Noise control should be treated with far more respect than it has right now. I think that's part of awareness of the noise sources. With our colleagues who are in other disciplines—managers and others—it should be emphasized that noise is often a multidisciplinary effort. It requires many different elements. We end up interacting with virtually everyone whether it's in the design or manufacturing process, a cost reduction request, materials, and so on. You are constantly meeting with different people, so I think we need to develop as positive a sub-culture as possible.

Centrifugal Blowers vs. Axial Fans

Question: Large equipment manufacturers are moving away from propeller fans to centrifugal blowers. Centrifugal blowers offer a lot of benefits—lower noise, lower power requirements, and smaller openings. Why or when will other industries move towards the use of centrifugal blowers? This is certainly true for earth moving machines, for example, where it has been proven that changing classical radial fans for a more or less centrifugal system would enable a 4 to 10 dB reduction. Will it apply to equipment of the same type, which I think is the case, or to other types of machines?

Answer: As far as centrifugal blowers, they are used in some cases. But a lot of times the geometry limits their use. A form of that type of fan is used in workbooks just because it is flat. Intel has some presentations showing what the effect of inlet restriction is on blower performance. The blowers have been used on some heat sink fans, but in other situations, the geometry of the system layout is not conducive to that type of fan. Some of the larger products, such as some network boxes that hold multiple storage units, do use blowers. So it's a match between the performance requirements of the system and the type of blower or fan used.

Comment: In the heavy truck and construction equipment world, the layout of the engine compartment and cooling systems is not conducive to blowers simply because it would require extensive re-design of the machine. It would be a situation where a centrifugal fan could be used if you are designing a new machine from scratch and you decided up front you wanted to implement a new cooling design. It would be very hard to retrofit an existing machine. In the heavy truck world this wouldn't happen. In fact, in heavy trucks you tend to rely a lot on intake air, so the amount of time the fan is running is relatively limited. And as they get smarter with controls, it will become even more limited in the future.

Comment: To address your point, in new product design at Ingersoll Rand we are now using centrifugal blowers. What we have found is that to be successful we have to change the housing to gain high-static pressure. With the blowers there is a steady flow, they can blow at a specific speed, and when you do that you can get a significant amount of sound reduction. How much reduction? About 5 or 10 dB. Overall, centrifugal blowers seem to be the best way to go; but you have to start with a new package design. You can't retrofit.

Comment: Improved performance of CPUs in the last year is incredible. But in a typical office you don't need this. The performance of the CPU is so high that you will never find a situation where you really need it.

Keyboard Noise

Comment: I have not tested any keyboards lately, but there has been significant progress in keyboards. Keyboards have become much of a commodity lately. One of the drivers is cost. About 15 years ago when people were making the transition from typewriters to keyboards, they liked to have feedback when striking a key. That's what they're used to hearing. Regarding keyboard noise, there are some keyboards that are fairly quiet, but manufacturers have them produce an audible click so that the person typing realizes that the key was registering. In some cases the sound actually comes through a small speaker. This is fine for the user but not for the bystander. There are a number of things that can be done. You can control the sound the key makes on the down-stroke and when the key comes back to its original position. Some of the larger keys like the space bar may have a spring or leveling bar that control how it sounds. My personal keyboard tester is my boss. He has big hands and attacks the keyboard quite aggressively. It's difficult to do a sound power measurement; you almost need to have a typing robot in order to do a sound power measurement.

Comment: Or people who are familiar with typing, like secretaries. If you choose a student and he uses only two fingers, is it quite noisy on such a keyboard. We compared this with the robot system which was developed many years ago. The result is different depending on the user, the normal person who types on such a keyboard. It's not easy to design a good robot. The results you get from persons who are typing need to be compared.

Comment: An excellent paper on

keyboard noise was presented by colleagues three years ago at the Istanbul INTER-NOISE. Our experience many years ago was that you can get repeatable measurements in the laboratory if you're using consistent force. That's what the robot is intended to do. However, in actual use I think we've all observed that the real source of the noise is the hand that is typing. There are some people who pound away. Many years ago during the typewriter studies, IBM wanted the operators to be able to understand that they made contact. In addition to the psychological factors a feeling that one is making contact is important. It's a simple thing to reduce that noise. There's ergonomics involved to make sure you are typing properly. I would also like to note that the comment about fan noise is not much of a problem for today's PCs.

The Future of PCs

Question: I have a question regarding notebooks or PCs. In the future it would seem that these devices—notebooks—could be totally silent. What are you expecting?

Answer: Currently my company not only makes business desktop PCs, but also products for clients that are basically passive systems and work over the network with the servers in a remote location. However, the need for cooling fans will not go away. As long as you have devices that consume power, you have to get rid of the heat. There's a class of desktop PCs called Ultra Slims that in the last few years have become almost like notebooks. They use a power brick. There are many local printers that will not have a power supply; they'll have a brick that is the power source. Using a brick removes one noise source. But you still have memory chips and CPU's that use more energy and run faster. Old memory sticks used to be measured in kilobytes but now they are measured in megabytes. These devices need more energy and that produces more heat. The need for fans will not totally go away. As far as using cloud computing, I'm not sure I want all my personal data on a remote server. There are articles about 130 million personal identification items being stolen by hackers. How much control over your personal information do you want to relinquish? In a business office where the employer is in control, the manager can dictate whether one has a personal computer or a remote terminal. Twenty years ago people were used to the mainframe computer and terminal model, so there is a trend to go back to a dumber or less powerful local device with control of the software at the server. From a computer IT management perspective, it's convenient to have all the software and data on small servers or on blade servers where they can be easily serviced. All the software updates can be controlled and access to the servers limited. But there's also a certain amount of human resistance to this perspective.

SESSION 3: Building Noise

Panelists

- **J. David Quirt,** NRC, Canada, Session Chair
  Overview of building noise
- **J. David Quirt,** NRC, Canada
  Noise transmission in commercial and residential buildings
- **Laymon Miller,** Consultant, U.S.A.
  System approach to the control of noise and vibration in buildings due to service equipment
- **Ralph Muehleisen,** Illinois Institute of Technology, U.S.A.
  Noise problems and opportunities in "green" buildings
- **Birgit Rasmussen,** Danish Building Research Institute (presented by David Quirt)
  Noise limits and building codes
- **Brandon Tinianov,** Serious Materials, U.S.A.
  Sustainable materials and new developments for building noise control

Presentations

J. David Quirt – Overview of building noise

Noise impacting the occupants of buildings comes from several types of sources. Quieting the source is feasible in some cases, but control of the transmission path to receivers is also common—and is the only option for some sources.

- For major outdoor sources (traffic, railways, aircraft, industry) noise control combines source emission limits with land-use planning and building adaptation to reduce noise penetration.
- For building services (HVAC, plumbing, elevators, etc.) noise control involves components' noise emission and the control of air-borne and structure-borne transmission to adjacent spaces.
- For occupant appliances (dishwashers, laundry appliances, etc.), products that are quiet from the user's perspective have been developed and marketed. Prediction of structure-borne transmission to adjoining occupancies is feasible for some types of construction, but data on vibration from appliances is limited.
- For noise from neighbors (voices, audio systems, footsteps) noise control focuses on the transmission path, via limits on air-borne and structure-borne transmission to adjacent spaces.

International harmonization of technical standards for measuring noise in buildings is limited—ASTM procedures are used in USA and Canada, but ISO procedures are used or are the basis for national standards in most other countries.

- Most ASTM standards for assessing sound transmission in buildings have near-equivalent ISO counterparts, but they differ in terminology and some details of testing procedures.
- ASTM standards for speech security and sound in open plan offices have unique features.
- Many new ISO standards have no ASTM counterparts, especially in the context of structure-borne flanking transmission, auditorium acoustics, and new measurement techniques.

Metrics for noise heard by occupants of buildings exhibit even more variety than the limited harmonization of ASTM and ISO measurement procedures.

- For sound transmission through separating wall or floor assemblies, ASTM and ISO have near-equivalent metrics for sound from air-borne sources (STC and R_w) and footsteps (IIC and L_{nw}).
- For sound transmission between adjacent spaces in buildings, including all transmission paths, ASTM established ASTC, NIC and NNIC (which have different normalization to allow for room absorption). ISO standards give four variants for absorption normalization and for each of these offer four choices for frequency-weighting; one subset of these resembles the ASTM metrics.
- For these metrics for sound insulation between adjacent spaces, recent research studies show that none of the ASTM or ISO frequency-weighting alternatives is a significantly better predictor of listener reaction for all common household sounds, though some are marginally better for specific sources. (See Park and Bradley, JASA, July & Sept. 2009.)
- There are similar sets of metrics in ASTM and ISO standards for insulation against outdoor noise and for noise from footstep impacts.
- Rating the impacts due to "children jumping" and the low frequency "thumping" due to adult walkers on lightweight floors may require additional measurement procedures and/or metrics. The "heavy/soft impact" test method and metric in national standards for Japan and Korea may satisfy this need, but further research is needed.

Regulating Noise in Buildings

- National building codes define minimum standards for acceptable buildings. Regulations alone are not well-suited to provide good noise control. Labeling schemes to market buildings with superior noise control give a useful extension beyond codes.
- The lack of "harmonization" of European descriptors in ISO 717 enabled a proliferation of unique national regulatory criteria using different metrics (which inhibits comparisons and international trade).
- Science-based re-evaluation of the available metrics is needed to provide an objective basis for convergence of international consensus to a justifiable subset of the current array of national regulatory criteria for both airborne and impact sources.

Classification Schemes for Rating (and Marketing) Buildings with Superior Noise Control Performance

Classification schemes have been created as national standards in many developed countries. Like the regulatory requirements, they use a variety of metrics and have nationally-chosen requirements to categorize performance into several classes that exceed the basic regulations, to provide a framework for marketing superior buildings.

In all cases, these classification schemes include criteria for insulation against airborne and footstep noise from neighboring dwellings, many include insulation against outdoor noise sources such as road traffic, and some include criteria for noise due to building services. No corresponding national standards have been developed in USA or Canada, but extensive studies of occupant preferences in Canada suggest a similar framework is well-suited to the North American market. Developing rational international consensus within technical community offers an opportunity to go beyond the minimum requirements, to facilitate better indoor environments.

Summary of Key Needs (which are explained in more detail in the subsequent presentations)

- Key areas for further research and development include:
  - extensive human response studies to validate selection of an optimal subset from the proliferation of metrics for transmitted sound of all types (airborne sources within buildings, outdoor sources, footstep sound including adults walking or children running)
  - studies to establish the effect of surface mobility on transmission of vibration and impacts from footsteps and appliances
  - credible sources for comprehensive and periodically-updated data on the performance of specific subsystems (such as floor coverings or ceiling assemblies) on airborne and structure-borne transmission of sound in buildings (preferably with generic descriptions)
- In the context of standards and regulations, key objectives include:
  - Consensus on an optimal subset of metrics for insulation against key noise sources
  - Harmonization of ISO and ASTM standards for measurement and prediction of transmitted sound, and extension of the prediction methods to lightweight constructions.
  - Common labeling schemes for buildings to supplement regulations by

facilitating marketplace differentiation of superior noise control performance

J. David Quirt – Noise transmission in commercial and residential buildings

For airborne sound sources (voices, TV, home theatre, etc.), the sound transmission rating for the separating wall or floor-ceiling assembly provides a first approximation to the noise transmission between adjacent occupancies (side-by-side or one-above-other) in a building.

- Extensive parametric studies have established credible data for transmission through most common wall and floor assemblies, described in terms of generic properties of components and assembly details. Some manufacturers publish data for assemblies with specific proprietary components. Data are scattered among many sites, each with information pertinent to constructions typical in a limited region. There are concerns that published data become misleading as products change, but the underlying technology is well-established.
- ASTM standards for laboratory and field measurements are used in Canada and USA; the resulting sound transmission class (STC) rating is normally quoted; corresponding ISO standards and ratings are used in many other countries. Terminology and technical differences between the ASTM and ISO standards are of minor technical significance.

In all buildings, more sound is transmitted between adjacent spaces than one would predict from the rating for the separating wall or floor assembly; in some cases this discrepancy is large.

- Sound isolation between adjacent spaces is systematically lower than one would predict from the STC rating for the separating partition, due to structure-borne (flanking) transmission of vibration energy via other room surfaces. ASTM standards have several measures such as the apparent sound transmission class (ASTC) to characterize this overall system response; similar ISO standards and ratings are used in many other countries.
- Construction errors or leaks can also reduce performance (and are included in ASTC).
- Building codes in Canada and the USA focus on the rating for the separating wall or floor—as if this were the only transmission path—and most designers and regulators in Canada and the USA were trained with this simplistic perspective. In other developed economies, standards and regulations use ISO ratings of system performance that (like ASTC) include all transmission paths and hence relate to what occupants actually hear. There are large variations in national regulatory and design requirements, but little technical justification for these differences.

For impact sound sources (footsteps or children running and jumping), there is also noise transmission between adjacent occupancies (side-by-side or one-above-other) in a building.

- ASTM standards for laboratory and field measurements are used in Canada and USA; the resulting impact insulation class (IIC) rating is normally quoted; corresponding ISO standards and ratings are used in many other countries primarily using the L_{nw} rating (which is closely related to IIC). Terminology and technical differences between the ASTM and ISO standards are of minor technical significance. There are large variations in national regulatory and design requirements, but little technical justification for these differences. Existing ASTM and ISO ratings do not deal suitably with low frequency "booming" sounds from lightweight floors.
- Most designers and regulators in Canada and USA focus on the IIC rating for the separating floor, as if this were the only transmission path. In other developed economies, standards and regulations use ISO ratings of system performance, like Apparent-IIC which includes all paths.
- Extensive parametric studies have established credible ratings for many common floor assemblies, described in terms of generic properties of components and assembly details.
- To assess improvements due to added floor coverings or the low frequency sounds from adults walking or children running (especially for lightweight constructions), additional research and enhanced testing methods are required.

For buildings with concrete and/or masonry structure, the science and the engineering tools for predicting the overall sound transmission between adjacent spaces are well-established.

- A full set of ISO standards to support such predictions have been established:
- Conventional testing using ISO 140 series (now morphing into new ISO 10140 series) gives data for direct transmission through separating assemblies.
- Other parts of the ISO 140 series of standards and the ISO 10848 series give estimates of flanking transmission involving other subsystems.
- ISO 15712 series use results from the above tests on subsystems, in a well-validated SEA calculation of system performance (including the combined effect of direct and flanking paths, for both airborne and impact sources).
- Commercial software packages implementing such calculations are available.
- ASTM standards include only a few of these procedures.

For buildings with lightweight framed construction, the basic science is well-established, but more research and development is required.

- Lightweight construction is a large (and growing) part of multi-family housing market for smaller buildings, especially in North America.
- Sound transmission in lightweight framed buildings is not predicted well by ISO 15712 approach.
- Extensive experimental studies in Canada have established suitable evaluation and calculation methods, and documented typical performance for most common wood-framed constructions.
- Knowledge gaps remain for some construction types, such as lightweight steel-framed construction or lightweight constructions combined with masonry and concrete assemblies.
- Software tools and data for more variants of lightweight construction are under development, but to advance this into common engineering practice there will be a need for both further evaluation of common types of construction, and adaptation of the technical standards such as ISO 15712 and its supporting subsystem tests.

For office buildings and for public buildings such as courts and hospitals, there are similar technical concerns, often expressed in terms of speech privacy rather than noise.

- Criteria and procedures focus on speech intelligibility appropriate in specific contexts:
  - Ensured speech security for spaces used for confidential legal or health-related discussions can be handled using the new ASTM E2638 standard
  - For open plan offices, a series of ASTM standards address speech “privacy”
- Some of these issues are also addressed (with minor differences) in ISO standards.

Summary of key needs:

- In the short term, key areas for further research include:
  - extensive human response studies to validate selection of an optimal subset from the proliferation of metrics for transmitted sound of all types (airborne sources within buildings, outdoor sources, footstep sound including adults walking or children running)
  - data for flanking transmission and for improvements due to added floor coverings, with emphasis on low frequency performance and lightweight constructions
- In the longer-term context of standards and regulations, key objectives include:
  - extension of standardized prediction approach (like ISO 15712) applicable to both heavy and lightweight constructions, with sufficient accuracy for design approvals
  - harmonization of ISO and ASTM standards for evaluating and predicting noise in buildings

Laymon Miller – System approach to the control of noise and vibration in buildings due to service equipment (Part 1)

With a system approach to noise control in buildings, we expect to do the job right the first time. This is by far the least expensive approach. I suggest nine steps in a total approach; there are concerns about all nine, but Steps 3-6 are the acoustical ones that we will pursue here.

1. Recognize the problem.
2. Identify the noise source(s).
3. Obtain noise data for the source(s).
4. How much noise is acceptable ? (introduce "noise criteria")
5. The noise reduction required, in decibels.
6. Determine the noise control treatment(s).
7. Produce drawings, specifications; communicate with everyone involved.
8. Purchase and Install the desired treatment(s).
9. Check Installation for acceptable performance.

Step #3.

This discussion is essentially limited to noise; the talk that follows will concentrate mostly on vibration. In the prepared talk, a representative mechanical equipment room (MER) of a large building was used as an example. Typical pieces of mechanical and electrical equipment were positioned in the room, and known or estimated noise levels were included for the equipment at their operating conditions. At this point, reliable noise level data are required; these data should be obtained from the equipment manufacturers or they should be measured or estimated or obtained from a known reliable source. In my own work over the years, I accumulated large quantities of this kind of information.

In the geometrical layout of this particular problem, I envisioned that the MER was enclosed in a solid wall of sufficient surface weight to keep the escaping noise acceptable for the area outside the MER. In a typical MER, massive (not light-weight) walls are a known requirement. I started with an 8-inch thick solid–core concrete block wall. Again, in my own work, I had determined (by measurement or calculation or literature search) the “sound transmission loss” (TL) of practically every conceivable type of wall (or floor-ceiling) combination. For more complicated geometries, an MER might be located directly above or below an office, in which case data for an acceptable floor-ceiling structure would also be required and used.

In this particular example, the total noise levels inside the MER (impinging on the room walls) were determined. Then, applying the TL of the selected wall, we obtain the noise levels outside the MER in the adjoining area. In an actual situation, a term “Noise Reduction” (NR) is more appropriate; it includes the TL of the selected wall plus a correction term that takes into account the area of the wall between the MER and its adjoining space, as well as the acoustic conditions of the "receiving room" that receives the noise from the MER. Refer to a textbook in sound for the details of this calculation.

Step #4.

This step introduces "Noise Criteria" or "Noise Criterion Curves" (NC Curves, we call them). There is a large collection of data and studies by Dr. Leo Beranek and others who have measured the background noise levels in all kinds of occupied spaces, and categorized those noise levels with the kinds of spaces where they are typically found – thus giving rise to the term "NC Curves" of noise. This then allows us to permit new intruding noise sources to make noise that can be somewhat immersed in the noise that is already present, and pass essentially unnoticed. This assumes that the new noise is fairly indistinguishable in its own sound character. NC Curves are typically identified by number, such as NC-25, NC-30, NC-35, and so on upwards to about NC-65. Background sound levels as low as NC-15 are often desired for fine music or concert halls. NC levels are found in most current text books on sound.

Step #5.

Taking the numerical difference (in decibels, in the different octave frequency bands) between the total noise levels inside the MER and the desired noise levels outside the MER in order to meet the Noise Criterion for that space, we have the "Noise Reduction" (NR) required for the wall and wall geometry.

Step #6.

With the "Noise Reduction" determined in Item #5 above, we confidently select the wall material and surface weight that will satisfy the NR requirement. It was on the basis of that kind of calculation that an 8-inch concrete block wall was selected for our example MER.

For an occupied office (with its lower NC Curve) directly under the MER, we would have a more difficult floor-ceiling structure, but it is done all the time---with special care and probably a heavier concrete floor slab and thicker ceiling than normally used. It is quite possible that the ceiling would be of 2-inch thick plaster, and resiliently supported under the floor slab of the MER (to have a typical "double-wall construction").

If still more noise reduction is required, it may be necessary to specify quieter equipment in the first place, or have a heavier wall with a higher TL, or apply more sound absorption material in the MER or in the "receiving space", or it might be preferable to apply some sort of noise control treatment to the specific piece of machinery that is making the dominant noise in the MER. These are all available as noise control treatments, and it often requires a special finesse to know and design the best treatment for the specific problem.

Of course, for this discussion, a very simple example was selected. The problems are usually a lot more complicated and the treatments require more complicated solutions.

In the prepared talk, I also included fan noise as a major problem in the ventilation system of buildings. This involves a more specific noise analysis as there are several noise sources (in addition to fans) in a typical ventilation system and there are available noise control treatments in the system as well. ASHRAE articles and data books and "Handbooks of Noise Control" provide data and procedures for calculating noise and noise control for fans and ducted ventilation systems.

Elevators and escalators are sometimes considered to be noise and vibration sources. For safety reasons, elevator installation specialists do not want resilient vibration-isolation mountings for any of their equipment, so the best noise control treatment is to surround elevator shafts with non-critical areas, such as corridors and non-critical work spaces. Escalators most often are located in expansive and somewhat noisy public spaces and usually do not represent noise or vibration problems. I have never had an escalator problem, and hence no suggestions.

The wide variety of mechanical and electrical equipment and locations in most buildings, and the wide variety of NC conditions that might be applied in their adjoining areas, make it difficult to anticipate setting noise and vibration standards and writing performance codes for their universal uses in widespread applications. Consider the following typical equipment, some of which are found in almost all large buildings: fans, pumps, motors, motor-generator sets, air compressors, large refrigeration compressors, packaged chillers, reciprocating engines, gas turbine engines, diesel engines, boilers, transformers, and cooling towers.

In earlier years, I gave short lecture courses around the U.S. and Canada on noise control, and it took three days to discuss this material. The Lecture Notes had 155 Tables of Data and 87 Figures of Details. It may take a great deal of time, patience, and ingenuity to compress that diversity of data, material, and applications into practical codes and standards.

Laymon Miller – System approach to the control of noise and vibration in buildings due to service equipment (Part 2)

In our above discussion of the "System Approach," we concentrated on noise control. Now, we have the more serious problem of vibration control—mostly from the same kinds of equipment. Let's assume that it is in the mechanical equipment room right over our heads.

Here we want to control both the feelable and the audible aspects of vibration; . . . and the real problem is that usually we can still hear the structure-borne noise long after we can no longer feel its vibration.

For vibration control, a suitable vibration isolation mount is installed between the equipment and the floor that it is sitting on -- or whatever surface that it might be setting into vibration. We will review only the most basic of fundamentals,....as vibration relates to noise; and we will be talking about steel springs and neoprene-in-shear as typical isolators. At the end, air springs will be mentioned.

This is not a theoretical paper, but there is one equation that is essential to keep in mind:

f_n = 3.13 x square root of 1/ S.D. Hz

where f_n is the natural frequency of the vibration isolation mount (steel spring or neoprene-in-shear) and S.D. is the "static deflection" (in inches) of the mount when it is loaded. As a simple example, if a spring is loaded with a 350-lb load and the spring compresses 2 in., the natural frequency of the mount with that load is about 2.2 Hz. Now, we must be certain that the "driving frequency" of the mounted machine does not equal (or come anywhere close) to that natural frequency. If it does, the system may go into serious vibration and could even damage the device. In fact, for "good" vibration isolation, the driving frequency should be at least 6 to 10 times the natural frequency of the mount, and preferably up to about 50 to 80 times the natural frequency for really important installations and situations.

In machines such as fans and pumps, for example, the RPM of the machine is usually the lowest driving frequency but it is not the most serious source of vibration. Usually, the blade- passage frequency is the more important source of vibration. As a simple example, suppose we have a 900-RPM fan with 10 blades, and this is mounted on springs that compress 2 in. under the load (with 2.2 Hz natural frequency, as mentioned above). The fan then has a driving frequency of 900/60 RPSec = 15 Hz and the fan blades provide a driving frequency of 10 x 15 = 150 Hz. The 15-Hz driving frequency for the fan RPM is about 6.8 times the natural frequency of the mount, and that is acceptable for RPM vibration. The 150-Hz driving frequency for the blade passages is then about 68 times the natural frequency of the mount, and this will provide very good vibration isolation – if every thing else is done properly.

When mechanical equipment rooms are located directly over or near offices or conference rooms or other relatively quiet spaces, it is often necessary to go even further in providing good, complete vibration isolation. One step is to mount the vibrating device on a heavy concrete "inertia block" (usually in the form of a slab under the fan-and-motor or pump-and-motor), which should have a mass of at least 5 or 6 times that of the vibrating load (even larger for a reciprocating device). Then, the vibration isolation mounts should be located at the outer corners or edges of the inertia block, preferably as far as possible horizontally from the center of gravity of the total assembly (including the concrete block) and as nearly as possible in a plane that contains the vertical center of gravity. Many vibration isolation manufacturers also have a line of metal forms for concrete inertia blocks for practically any size desired, and they can be delivered to the job for concrete filling. In the prepared talk, slides were shown for these various components of standard vibration-isolation mounting systems.

In very special noise-control problems, it is often necessary to have a large clearance (2- to 4-in.) under large-area concrete inertia slabs so that there is minimum "air-coupling" between the bottom of the inertia block and the floor slab under it – not to mention that the larger air space reduces the possibility of building trash being swept under the block and causing a short-circuit in the isolation system.

Ducts and piping connected to these major vibrating systems also conduct vibration, and must be provided with proper protection. Typically, vibration-isolating ceiling hangers or floor-mounted vibration isolation mounts can provide this necessary added protection; and these should be used for large distances from the actual equipment. Pipes conduct vibration along their pipe walls; so, reinforced neoprene pipe connections and expansion joints are also a requirement, especially for large piping. They should be installed in the piping very close to the vibrating source. Piping still carries vibrational energy in the liquid inside the pipes; and it is important to keep it away from rigid contact with building structures. So these pipes must be carefully isolated from building floors and walls – to prevent "structure-borne" noise transmission. Vibration isolation manufacturers can provide all sorts of these isolating and mounting devices. Electrical conduit connected to vibrating equipment should be of flexible armored cable for a short distance or have one or two large circular loops that help absorb and reduce vibration transmission.

In residential situations, if plumbing noise is a problem, pipes should be wrapped with several layers of 2-inch-wide fiberglass cloth tape, to build up to about 1/4-inch thickness, and that wrapped portion attached to the wall under a pipe clamp. A ribbed neoprene pad wrapped around the pipe and clamped, might do as well. Also, if water faucets squeal when they are turned on, the water pressure might be higher than necessary, and perhaps the squeal can be reduced with a pressure regulator valve.

On the subject of ceiling hangers, here is a very essential application; this was mentioned in the earlier talk on noise.

When a quiet space is located directly under a known noisy area, it is often necessary to install a heavy ceiling suspended on resilient ceiling hangers to help reduce the noise from that overhead space. A 2-in. thickness of plaster or two or three plies of dry-wall gypsum board will often serve this purpose. In effect, this becomes "double-wall construction", with the overhead floor and the heavy ceiling serving as the two members of the "double-wall" system.

We are not structural engineers, but for mechanical equipment rooms or floors, we recommend dense concrete and large floor thickness in order to provide a massive, rigid base for supporting all of this equipment and its concrete inertia blocks. Where there are large spans between columns, floor deflection becomes a factor, and the vibration isolation mounts must have even larger static deflections.

When vibrating equipment is mounted directly on the floor or on steel springs directly over quiet spaces, the metal-to-floor connection can transmit high-frequency structure-borne noise. Ribbed neoprene pads and waffle-pattern neoprene pads may be placed under the foot of the equipment or under the base-plate of the springs to help in reducing high-frequency noise transmission.

If you ever bounced up and down on an inflated automobile inner tube, that was an air spring. (Do you even see automobile inner tubes any more?) Technically, air springs are much more sophisticated and can handle heavy loads with high pressure air. When designed and used properly, they are very good and serve special purposes. Slides (borrowed from Eric Wood at Acentech, Inc.) showed two large, massive concrete inertia blocks installed on air springs to isolate test beds from nearby earth-borne or structure-borne vibration. One particular air spring (by Kinetics Noise Control) was supporting a 60,000-lb load with a natural frequency of 1.25 Hz.

Several years ago, I had at least three problems that required a vibration-isolated base (but not nearly as large and heavy as the inertia blocks shown in Eric's slides): one was in a medical university requiring a vibration-free mounting for an electron microscope, one was for a mass spectrometer in an industrial process, and one was for a space-age inertial guidance system. In the first two, before the isolated bases were installed, a banging door anywhere in the building could ruin their readings.

Large roof-mounted cooling towers frequently have so much vibration caused by their propeller fans, that they cause serious vibration in their own buildings. In the prepared talk, I showed slides obtained from Reggie Keith (of Hoover & Keith Inc, in Houston). In his "Method 1", the whole tower is vibration-isolated with large steel springs. In his "Method 2", the propeller fan and its drive motor and gear are isolated from the cooling tower proper. Reggie even sent me one slide that was labeled "Very Old Example of Method 2". It was a photo of one of my jobs about 50 years ago. Whether it is Method 1 or 2, if the cooling tower is located immediately above office spaces, it is essential that stacks of ribbed neoprene pads be used to help reduce the higher frequency noise of the waterfall into the basin.

I would like to mention two important, "do's" and "don't's" on the subject of vibration isolation. First, "DO" design the installation so that you can clearly see the isolation mounts. If they are hiding and you can't see them, you may not know whether they are working properly or not. My second "DO" is this: If springs are to be used, "DO" use unhoused, free-standing springs. Some springs are contained in housings, and there is only a small slot in the side of the housing to see the spring inside. If the spring is tilting sidewise, it might be scraping on the inside of the housing and not performing at its best. The manufacturer knows that this might happen, so pieces of rubber are located inside the housing, so the spring rubs against rubber pads. This, too, can reduce performance. It is best to avoid housed springs.

There are three other possible noise and vibration problems in buildings that could be considered, but there is not enough time here.

1. Floor-to-floor impact noise in multi-family dwellings. There are available "floating floor" designs for both wood and concrete floors that can be applied to buildings either before or after they are built.
2. Service equipment such as elevators and escalators. Mentioned briefly in the first talk on noise.
3. Protection of buildings from earth-borne or structure-borne vibration caused by nearby railroads, subways, and highways. I have worked successfully on a few of these, but they are major problems and require more discussion than available here. The same applies to an even greater extent for protection against seismic disturbances, such as earthquakes.

The material presented here is based on many experiences gained as an acoustical consultant to architects, engineers, civic groups, building owners, manufacturers of acoustical products, and other interested groups. And, the problems and treatments named here are among the simplest ones. We must often be detectives to find the real cause of a problem. There is such a wide variety of equipment and applications, I believe that acoustical consulting represents an essential part of engineering and architecture.

My two discussions of noise and vibration of building equipment do not address the problem of producing applicable noise codes and standards. However, they do highlight the wide range of equipment typically used in most large buildings (and in many smaller buildings) and the various locations that might require a limit on the relative acceptance ("noise criteria", as discussed briefly) of intruding noise into the environment. This emphasizes the problem of detailing codes and standards for this wide variety of noise sources and locations. It is my opinion that this will require large amounts of time and infinite patience. I offer my thanks and gratitude to those who can accomplish this.

Ralph Muehleisen – Noise problems and opportunities in "green" buildings

What is a "Green" Building?

"Green" buildings are supposed to be better for the environment (i.e. more sustainable) than conventional buildings. During construction and operation they use less energy and water and destroy less of the environment. They should also provide a better indoor environmental quality (leading to better worker satisfaction and performance).

Why are "Green" Buildings Different?

Green building design aspects focus on energy use, water use, and sustainable materials. They make optimum use of:

- Natural ventilation
- Daylight and passive solar heating
- Radiant heating/cooling
- Wood and stone and less use of fiberglass or mineral fibers
- Glass for daylight integration and views of the outside world

Green buildings also use fewer interior walls and partitions.

LEED

Leadership in Energy and Environmental Design (LEED) rating systems have been developed by the U.S. Green Building Council (USGBC) which is the most popular green building rating system in the U.S. Other rating systems include Green Globes and Build it Green. LEED has different rating systems for the following different types of buildings:

- New construction
- Existing Buildings / Operation and Maintenance
- Core/Shell + Commercial Interiors
- Schools, Healthcare, Retail

Acoustics in LEED

Only LEED for Schools and the soon to be released LEED for Healthcare have any acoustics. The LEED for Schools requirements are a reduced version of ANSI S12.60 Classroom acoustics, and the LEED for Healthcare requirements are a reduced version of the acoustics in AIA Guidelines for Healthcare Design. The most popular LEED rating systems (NC and EB/OM) have no acoustics whatsoever. As a result, design teams have no incentive (from the rating system) to design for good acoustics or even consider them within the design phase

Surveys of Building Performance

A survey was conducted of more than 400 buildings that included LEED-rated "green" buildings and new non-green buildings. The questions asked dealt with acoustics, thermal comfort, air quality, lighting, cleaning/maintenance, office layout, and overall workspace. Acoustics is the only category where the performance significantly decreased compared to non-green buildings and it is the category with the lowest ratings. In short – "green" buildings have worse acoustics.

Acoustics Complaints

The major acoustic complaints in LEED-rated "green" buildings concerned people talking in neighboring areas, people overhearing private conversations, and people talking on the phone. Ringing telephones were a lesser complaint. There were minor complaints about mechanical noise (heating, cooling, and ventilation systems), office equipment noise, and outdoor traffic noise.

Causes of Poor Acoustics

In "green" buildings there are several causes for poor acoustics. These include:

Natural ventilation. Natural ventilation uses small room-to-room pressure differences to drive air flow through holes in walls and open windows. This reduces the energy use to draw and move air in ducts and provides higher quality air to occupants. This results in reduced HVAC noise which can be good but can sometimes be so quiet as to reduce speech privacy. It also results in poor sound isolation from outside to inside and room to room with lower cubicle wall sizes.

More use of daylight and passive solar. Green buildings use a lot more sunlight for illumination (day lighting) and heating (passive solar). More sunlight means more windows and some use of glass for internal walls to allow more interior sunlight penetration. As a result there is reduced indoor/outdoor sound isolation, reduced interior sound isolation, and more acoustically-reflective surfaces on room walls and ceilings (especially with skylights).

More use of radiant/heating and cooling. Radiant heating and cooling is being used more for improved energy efficiency and improved thermal comfort. As a result there is reduced HVAC noise; but, more exposed metal and concrete mean more reflective surfaces. However, thermal mass which is used for energy savings can improve sound isolation.

Use of Sustainable Materials

"Green" buildings use more sustainably farmed wood, metal (recycled and recyclable), stone, and concrete than conventional buildings. This means there is a reduced use of acoustic ceiling tile and absorptive panels and a reduced use of carpeting. Note: acoustic tiles, panels, and carpeting all are being made in far more sustainable ways so the trend away from them might be changing.

Advantages of "Green" Buildings

Design teams of "green" buildings work in a more integrated fashion which means better design team communication. Bad acoustics from poor communication amongst the design team is less likely, and more team members understand the performance goals so acoustics goals are known by all. Because there is more use of high-mass construction (concrete, filled CMU) in walls and floors there are better sound isolation opportunities, and less forced air HVAC means less HVAC noise. Occupants become aware of acoustics through education and post-occupancy surveys

Major Needs

There is a need to get acoustics into the criteria for green building rating systems, but this will be difficult because it does not have a direct monetary/sustainability measure. There is a need to educate architects and engineers on the importance of including acoustics in the design, even if the rating system does not—to make them aware of the implications of poor acoustics (unhappy and unproductive applicants) and to make them understand that some things cannot always be fixed afterward.

Summary

"Green" Buildings usually have worse acoustical performance than conventional because rating systems do not incentivize good acoustics. We need to change that. Green building designs also tend to remove sound absorbing materials and reduce isolating construction. However, "green" buildings also provide some good opportunities for improved acoustic performance through coordinated, integrated design teams. The high-mass construction provides opportunity for improved sound isolation and creates a market for sustainable acoustical materials.

Birgit Rasmussen – Noise limits and building codes

Building codes in Europe include provisions to control noise from several types of sources, to address potential adverse effects related to health, occupant comfort, and avoidance of potential conflicts. [1, 2, 3, 4, 5]

- Sources of serious noise annoyance identified in recent surveys in European countries include: local road traffic, neighbours, aircraft, industry, railways and motorways.
- Effects of noise on health have been documented in many publications.
- Acoustical comfort for occupants of dwellings requires both an absence of unwanted sound from elsewhere and the opportunity for normal activities without annoying other people.
- To obtain acoustical comfort, criteria for building performance must be fulfilled for airborne and impact sound insulation between dwellings, for noise from external sources such as traffic, and for noise from technical installations such as plumbing or HVAC systems.

Regulatory requirements for controlling noise from neighbours in multi-family housing vary widely between countries, using both different descriptors and different numerical limits. [5, 6, 7]

- A comparative study has been carried out investigating regulatory requirements in 24 countries, plus supplemental sound classification schemes in 9 countries.
- Requirements for sound insulation use descriptors defined in ISO 717 Parts 1 and 2, and tests using ISO 140 parts 4, 5, and 7. Noise from technical installations is tested following ISO 10052.
- For airborne sound from neighbours, ISO 717-1 provides 15 descriptors, and for impact sound a choice of 6. National regulations have selected a variety of these.
- Requirements for row housing differ from those for multi-storey housing in some countries.
- For airborne sound, approximate conversion to a single descriptor (weighted apparent sound reduction index, R'_w) indicates that the required R'_w varies from about 50 to 60 in national requirements (a range of 5 dB for multi-storey and 10 dB for row housing).
- For impact sound, approximate conversion to a single descriptor (weighted apparent normalized impact level, $L'_{n,w}$) indicates that the required $L'_{n,w}$ varies from about 42 to 63 in national requirements (a range of 17 dB for multi-storey and 22 dB for row housing).
- Low frequency descriptors (important for lightweight construction) are used only in Sweden.
- A European Action, COST TU0901, has been established to cooperate about harmonization.

Regulatory requirements for controlling noise intrusion through facades also vary widely between countries, using both different descriptors and different numerical limits. [8]

- Limits are defined in more ways: minimum façade sound insulation as a function of outdoor noise level, maximum indoor noise levels, or maximum "night event" levels combined with other criteria. All of these lead to sound insulation criteria for the façade.
- For façade insulation against noise from outside a variety of descriptors are defined in ISO 717-1, which offers 27 choices! (not counting 1/1 octave descriptors and those with extensions related to the type of source).
- The descriptors applied for indoor noise level limits applied in some countries are NOT defined in ISO 717.

Current trends are promoting changes from current regulatory criteria [5, 6]

- There are more intrusive noise sources, including those due to neighbours' activities.
- Demand for increased use of lightweight constructions will force a shift to descriptors that include low frequency performance.
- There is increased demand for higher quality, including acoustic comfort.
- It is widely recognized that more flexible criteria are needed to supplement legal minimum requirements – which could be addressed by classification schemes that offer a framework to design and market buildings that perform better than is required by regulations.

Classification schemes for acoustical comfort have been developed in nine European countries [7, 8]

- Most classification schemes are developed as national standards.
- The existing classification schemes all deal with insulation from airborne and impact sources in neighboring units within a building, and most of them include noise from outdoors and from equipment.
- The nine schemes use several different descriptors. Some use descriptors that include low frequency performance, others don't.
- The nine schemes have different number of quality classes and class intervals.
- Relationship to regulatory requirements varies, but most have two classes that are significantly better than regulatory minimum.
- With approximate conversion to common descriptors, the required R'_w for the top category varies up to about 65, and for the second category from up to about 60. The criteria for impact sound show larger variation.
- A European Action, COST TU0901, has been established to cooperate about harmonization.

Summary:

- Many descriptors are used for control of airborne and impact sound from neighbours.
- There are large differences in regulatory requirements, especially for impact sound.
- There are also large differences among national classification schemes to label buildings with superior performance.
- For lightweight buildings, low frequency sound is important, but requirements for low frequency performance have not been adopted in most countries.
- Harmonization of descriptors and classes are important to facilitate exchange of experience and reduce barriers to trade.

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Brandon Tinianov – Sustainable materials and new developments for building noise control

Specifying green acoustical materials is poorly understood and difficult to implement from the acoustical expert's perspective. One prime reason for this is that the accepted definition of "green" is poorly understood by the acoustical community[1]. The most widely accepted interpretation of the term does not refer to building materials that have a high recycled material content or is made without the use of toxic chemicals. While both of these elements can be important green building material features, the concept of green should and often does, extend to the project whole. Taken together, the material and design implications extend beyond material content to water consumption, energy use, and to the health and wellness of the occupants. These larger considerations are reflected in the most prevalent green rating system, the Leadership in Energy and Environmental Design (LEED) rating system as established by the United Council (USGBC).

Within the framework of a larger, holistic building system, an acoustical material can be considered green on three levels: a) its contribution to the health and comfort of the building occupants; b) environmentally preferable nature of its components or manufacturing process; c) its secondary performance features that have a positive impact on other building systems.

An acoustical material's contribution to the occupants' comfort is second nature to a noise control expert. Appropriate materials placed in the design can dramatically increase the communication and productivity of office workers and enhance the comfort of residents or patients. These materials cannot be manufactured and installed without negative impact to the environment, but that impact can be weighed against the benefits of a building that is operating more efficiently.

One example of such impact is a Detroit-based insurance company that designed its new office with improved privacy and new state-of-the-art environmental systems. Evaluations showed a 137% decrease in time required to process client paperwork, a 9% drop in errors and defective claims, and a drop in absenteeism to 1.6 % from 4.4 % [2]. As shown in a research study across a population of buildings, including 400 manager interviews, respondents estimated a 26% organizational improvement with the implementation of noise reduction strategies [3]. For this reason, specifiers and consultants should work closely with the design team to ensure that they understand these benefits as part of their higher profile green rating system rubric. The second important factor of green acoustical materials is its material composition or manufacturing process. In most green rating systems, the constituent materials of a product are considered green if it contains recycled content (20 – 100% is preferred), uses rapidly renewable materials, or uses certified wood products (See Table 1 below).

The term 'rapidly renewable' refers to plant products that have much shorter planting to harvest cycles than traditional lumber products. Specific material examples include bamboo, wheat, straw, and at times, young soft woods for use in chip board and oriented strand board (OSB) (see Figure 1). Credit for such materials requires a certification from the manufacturer. Likewise, traditional soft and hardwood products can be certified as having been harvested by sustainable forestry methods. The woods

Table 1: Example of products with quantified recycles materials content (Source: A. Costello, Armstrong World Industries)

Material	Recycle content	Uses
Mineral Fiber	Up to 80% total	Ceilings, wall panels, furniture partitions
Slag wool	PI	
Newsprint	PI or PC	
Recycled Ceilings	PC	
Fiberglass	30-75% (PC and/or PI)	Ceilings, wall panels, insulation
Metal		Ceilings, suspension systems
Ceilings	25% PC is typical	
Suspension systems	30-80% PC	
Drywall		Walls, ceilings
Synthetic gypsum	Up to 100% of drywall core (PI)	
Recycled boards	Up to 25% (PC)	
Recycled paper	Up to 100% of paper (PC and/or PI)	
Wood Veneer on MDF	Up to 100% of MDF core (PI)	Ceilings, walls

also bear a manufacturer's certification and chain of custody [4]. Consultants and practitioners should avoid products with general claims of greenness without using specific material features and supporting documentation (see Figure 2).

The final facet of an acoustical material's ability to contribute to the green objectives of a building is its secondary performance features, beyond those of acoustics. Such features may include thermal insulation allowing for a reduced HVAC load and downsized system; a light reflective surface which increases the level of ambient daylighting in the space; increased fire suppression, or other. One rarely considered green strategy is to use innovative acoustical materials or designs that require far less construction materials (e.g. stud walls with isolation clips or damped panels that may replace heavy masonry or poured concrete construction). Information and guidance on such secondary benefits is scarce—acoustical experts are advised to become involved in the green design process and look for opportunities for their acoustical treatments to benefit other systems. As an immediate resource, some product manufacturers are currently able to highlight the secondary benefits of their products. For example, Table 2 shows several examples of ceiling tiles that accomplish both echo reduction via high Noise Reduction Coefficients (NRC) and high light reflectance (LR). A third, undocumented benefit may be that the products may contain recycled materials in the product. Three, four, or five benefits may validly be attributed to a single product or design strategy. If fact, many green rating systems encourage such an approach.

With regard to understanding the green attributes of acoustical materials, the conclusion is complicated. Acoustical materials have a primary function of acoustical comfort, which should be (and often is) recognized as a basic tenet of a green building. Materials should be specified to that primary aim. However, acoustical experts can make informed material decisions and participate with the green design team to further enhance the green objectives of the project. These additional objectives can include using materials with low environmental impact materials and those with secondary building system benefits. These additional objectives can include using materials with low environmental impact, and those with secondary benefits to the building system.

Figure 1: A manufacturer's example of recycled content and traceability of their source materials (Source: Tectum Inc.)

***MR Credits 4.1 and 4.2*: Recycled Content** - The Tectum Finalé Wall Panel has 40% Post Consumer recycled content by value and 8% Post Consumer recycled content by weight. Tectum Fabri-Tough Wall Panels have 8% Post Consumer recycled content by weight as the Hytex Acoustical Fabric is 100% recycled material. Fabri-Tough Wall Panels have 23% Post Consumer recycled content by value. Finalé Fabri-Tough has 19% Post Consumer recycled content by value. Tectum E has 11% recycled content by value, as the EPS core is 60% recycled material.

***MR Credit 7*: Certified Wood** - Tectum products are made from Wisconsin Aspen wood fibers, harvested in Wisconsin by American Excelsior Company. American Excelsior Company is FSC and SFI certified. A chain-of-custody letter is available upon request.

Figure 2: An example of poorly detailed or substantiated green claims (Source: internet search)

- *Aesthetically Appealing, High Quality, Decorative Look*
- *Enhances & Optimizes Acoustic Environments*
- *Outstanding Acoustical Performance*
- *Reduces Noise Reflection and Echoes*
- *Easy to Install - Immediate Results*
- *Handcrafted in USA*
- *Cost-Effective Sound Control*
- *Earth-friendly. Made from Natural and Recycled Materials*
- *Available in a Wide Variety of Shapes, Sizes, Multi-layers & Mobiles*
- *Customizable with your Logo, Image or Photo - Compliment any Decor*

GO GREEN
Smarter Sound Control Solutions

References

1. While the words 'green' and 'sustainable' do not have the same precise definitions, they are often used interchangeably—both in popular and technical literature. They are used interchangeably here as well to imply 'environmentally preferable over traditional products or systems.'
2. American Society of Interior Design, Sound Solutions: Increasing Office Productivity Through Integrated Acoustic Planning And Noise Reduction Strategies, 2006.
3. American Society of Interior Design, The Impact of Interior Design on the Bottom Line, 2000.

Table 2: For multiple NRC ranges of interest, there is a high LR option (Source: A. Costello, Armstrong World Industries)

Texture and substrate	Measured NRC range	Measured LR range
Smooth, painted veil on slag wool	0.65 – 0.80	0.89 - 0.90
Smooth, painted veil on fiberglass	0.80 – 1.00	0.82 – 0.90
Sand-like or dimpled on slag wool (standard absorption)	0.45 – 0.50	0.82 – 0.88
Sand-like or dimpled on slag wool (highly absorbing)	0.60	0.85
Sand-like or dimpled on cast mineral wool	0.70	0.77
Textured or embossed on slag wool	0.55 – 0.70	0.82 – 0.86
Fissured and punched slag wool	0.50 – 0.65	0.81 – 0.86

4. At this time, the USGBC's LEED rating system only recognizes the Forest Stewardship Council (FSC) as a valid third party wood certifying agency.

Discussion

Lightweight Building Construction

Question: Please comment on Birgit's statement that the permission to construct lightweight buildings in Europe has come more recently than it has in North America. Apparently it has come selectively among different European countries. When did lightweight construction come to Europe?

Answer: One of the talks in the session on lightweight construction yesterday said that it began nine years ago. It may have been earlier than that in some countries. But there are still countries where, for multi-family dwellings, it's still not allowed. In Austria, for example, it's still being required that heavy concrete and masonry construction for multi-family housing is used. But there certainly is a very strong motivation to move towards lighter-weight construction and perhaps not as lightweight as wood frame construction or light steel frame construction. There are choices such as steel and concrete composites which in that nebulous middle ground between the heavy constructions where one can accurately predict the performance of the system and the lightweight constructions where we are still gathering scientific information.

Comment: Lightweight may be steel in load-bearing constructions, non-bearing gypsum stud walls, or wood in bearing or non-bearing constructions. In Sweden wood construction in high-rise buildings was forbidden for many years until rather recently. Now this is changed and dwelling houses with five or six floors are allowed. They are built successfully and with good sound insulation. This is a new development. Other lightweight constructions with gypsum boards in non-bearing walls have been used for a long time and have been allowed also for separating walls between dwellings for many years.

European Classification Systems

Question: What has been the driving force for the classification systems for sound insulation in Europe?

Answer: My sense is that in many of the countries people are not aware that there is a market for better buildings. There are a lot of people who want better buildings and who want to have some way of assessing what they are buying. In the same way that energy efficiency ratings have become common for many types of home appliances, a labeling scheme for buildings tells people what they're getting so they can make a rational judgment about spending their money is very desirable. The people who care about the rating are prepared to spend for it.

Comment: Sweden, with its social welfare system, developed economic subsidies for housing quite some time ago. For many years, the subsidies for dwellings were the basis for the financing of new buildings. The rules did not promote higher quality than the minimum requirements demanded. There was no interest in building houses with higher acoustical quality as this had no positive effect upon the economy. This financing system was changed 20 years ago. In 1993 when a classification system for dwellings was proposed, and this was welcomed by the building industry because that could create an economic incentive to build with higher quality. A classification standard was developed very rapidly with three classes. Class C corresponds to the minimum requirements. Class B is approximately 4 dB better, and Class A another 4 dB better. Builders soon found out that customers in Stockholm would not buy apartments that are not at least Class B.

Green Buildings in North America

Question: Please comment on the corresponding attitude of the building industry in North America.

Answer: The building industry in North America is not so dissimilar. They fight tooth and nail to stop changes in the legislation and to keep the regulation requirements as low as possible. But many of them know how to build much better and would welcome a system that would enable them to market more readily the better things that they build. It's the same way in which the energy efficiency rating came about, and it's precisely the situation with LEEDS where the LEEDS rating system for green buildings has several different grades and has point systems to provide more of an award for superior performance. A classification scheme for sound insulation in buildings is fully consistent with the requirements that the high end of the market has been looking for, but the acoustical community here in North America hasn't provided the designers and buyers with the necessary acoustical tools and standards.

Comment: One of the impediments to having acoustics appear more often in the green building rating system has been the lack of a consistent standard that the community has agreed upon. We have a standard to measure, but we don't have a standard to tell us what it should be. If one considers ventilation, in North America ASHRAE 62 that has a listing of what is required in terms of airflow. There's a standard on how make measurements. There's a standard of what the levels should be. With thermal comfort and ASHRAE 55 gives the humidity range and temperature range for a certain percentage of people to have thermal comfort. There is nothing on acoustics that links people's annoyance or acceptability to a specific sound level whether it's ASTC or OITC. That's a missing link, and the people in the U.S. Green Building Council say that they'd be happy to include acoustics if we could point to something to be given to the designers as a requirement. So it's on us.

Comment: I agree completely. Daylighting is the same. But other building requirements have established sets of indices and readily usable tools to calculate how the complete building is going to perform in terms of those various indices. The ability to predict the sound insulation of the complete system which is needed for a meaningful prediction of what occupants will hear is fundamental to a green building system where they use models for the different disciplines for the integrated design process. We haven't provided the tools; we haven't provided a coherent consensus on rating schemes, so they can't include acoustics.

Comment: We are working with people who are intelligently involved in noise problems. They know that there are certain people who work on these problems and can find solutions, but what percentage of the population doesn't know that there is knowhow around the world to help solve noise problems? We need some concerted motivation on the big scale for people who don't know that noise is harmful and noise is disagreeable and noise has bad attributes. Let them know there are solutions to noise problems. Until they make their demands known—which means paying for improvements—we'll never get them. There are some idealistic people are working on the codes, but 50 percent of the public doesn't know about codes, don't know about noise control. They may not know that noise control is possible. We need concerted effort by a respectable organization that has reliability, motivation, and visibility so people know that's a organization you can depend on. We need that kind of motivation.

Building Codes

Comment: In Birgit's paper it showed the variety and lack of consistency in building codes in the 29 countries of the European Union. She pointed out that Austria has the toughest requirements, and other countries may be similar. They have their own requirements, and if a builder erects a substandard dwelling in Vienna, some authority will get after them and not allow them to build any more dwellings or to sell them. This is motivation for the building industry to keep up to at least a C grade or the lowest grade standard for that particular country. What have we in North America except voluntarism? Volunteers can spread the word that there are experts around; but if a fly-by-night builder is able to sell a substandard dwelling it's caveat emptor. Am I incorrect?

Comment: I think you're correct that the current situation is such that under the letter of the law it's not altogether clear whether in Canada or the United States the building code is enforceable in the sense of requiring a specific level of sound isolation. This is partly because it focuses on design requirements, not performance requirements. So you must pick a design that should, in principle, give the minimum performance. North American building codes focus just on the rating for the separating assembly but don't use a rating like ASTC that applies to the performance of the complete system. The building codes request builders to pick part of the system that will be good enough if the other parts are okay, but the builders don't have to worry about the other parts.

Comment: In Israel there are a variety of courses which reflect the standards of different countries, different levels of economy, and different varieties of development in those countries. The market will do its job which means those varieties of standards goes from down up. It will generate a demand from the public, the people who seek standards, for better standards and a better life. In their effort to improve their standard of living, I believe that the people will win. There are two forces—the people and the government—and in time the demand for improved standards rise to those upper limits.

Comment: From time to time I talk to a knowledgeable consultant about HUD, the U.S. Department of Housing and Urban Development. I always thought there were some minimum requirements in the United States under HUD regulations. The consultant says there are none; there are no requirements for sound insulation in multi-family dwellings. Further, the guidelines HUD uses are good guidelines as written by Ted Schultz in the 1970s, but there have been no updates. A few years ago I tried to find somebody in HUD who would talk about acoustics, but nobody in the entire department knew anything about the subject.

Comment: I believe the consultant is both correct and incorrect. The guidelines that were developed in the U.S. HUD design guidelines were enforceable at the time there was the EPA noise office because they had the responsibility for buildings that were constructed with U.S. government money which were public housing facilities in some of our major cities. That money dried up in the early 70s, and there has been no more public housing built with HUD funds. Buildings constructed by local or city governments do not necessarily follow HUD guidelines. That's why the consultant is right. Although you may be able to file a civil lawsuit in the same way that you can with the American Disabilities Act—it's a civil code. If you're involved in the construction of a public school, for example, nobody does inspections to check adherence to the guidelines. However, you can sue the entity and they have to make the changes if it's found the building was a poor design. That may still be the case with HUD regulations. If you live in public-subsidized housing, you can sue and the building owners will have to address the problem. But it's definitely not in the building code. Building codes in the United States are driven 100 percent by insurance and public safety. It started with the insurance companies refusing to insure a building that did not have fire protection. When the building codes were initiated there were groups in American that worried about public safety. Consider the National Electric Code with all its intricacies. Any change in that code has to be driven by safety. Will you show a reduction in the number of lives lost, people injured, or building costs in terms of fires that may be started or safety of the building somehow. That is the driving force behind building codes as we have them throughout the U.S. Performance codes show up in guidelines like the LEED and some cities have them. Performance codes are always a separate situation, and that's where we are going to have to fit in, to get into performance-related codes because it's going to be difficult to show the same level of detriment to the society with noise problems disturbing people's sleep. We know it's a problem, and maybe it is a public safety issue but not the same as a fire burning down their house. Not the same as not having enough ventilation so that people pass out, not the same as having a carbon monoxide buildup from a faulty installation. Noise is going to be much harder to include in the U.S. building code. Is Europe different that way?

Comment: That's my question also. The building codes in North America are strictly designed. In other words, to get a building permit, you've got to submit the design of the building to the authorities. Once the builder gets the building permit, he can erect the building. There's no performance aspect of the building code; whereas in Europe, as I understand it, there are performance standards that are established that are a part of the building code so that a follow-through on the design is carried out. In North America it's only the building inspectors who get involved at the end of a project, and they're not checking to the original design. Am I correct?

Comment: Yes and no. Many parts of the design are approved simply by looking during the beginning phase. For the electrical installation, there are no performance requirements. You're just checking to see that the design is implemented. However, things like ventilation rates are checked in bigger commercial buildings; but it depends on the situation of the building. The checking that is done is just to make sure the construction matched what the design was but not checking the performance. Ventilation requirements are changing, and more cities have energy codes with strict energy requirements that are beyond just descriptive. Exterior rooms must have fewer windows, and the energy performance must be documented—so many BTU per hour or less.

Design versus Performance

Question: What about transmission loss between adjacent dwelling units?

Answer: For transmission loss, in Canada and the USA, the regulators do not check the performance.

Comment: In Sweden real change occurred when we went from design to performance. In the previous financing system, the responsibility for the design was shared between the authorities and the builder. Now the builder has the full responsibility. That made the change. The sound classification system is based on measurements in the finished building. It must be proven through measurements that the building fulfills a higher class than C.

Question: If the adjacent dwelling units cannot fulfill the design specifications in Sweden, are they allowed to rent, sell, or have the building occupied?

Answer: There are very few buildings in Sweden that are not occupied. Our newly built apartment houses have reasonable sound insulation quality.

Comment: We are facing the phenomena of "green" buildings now. The "green" buildings approach is to check the air conditioning system, the waste, the soil, the energy, and the acoustics. This is the result of public pressure, from down up. The higher the standards, the greater the need for improved acoustical design.

Comment: The reference to the "green" building system is, I think, a perfectly valid one. Marketing "green" buildings seems to be succeeding despite the fact that it is a design requirement almost entirely. Codes are moving now towards post-occupancy evaluation, but in the early stages it's been purely in terms of design and has caused a revolution in design and in what's being built. How perfectly this is being achieved isn't clear, but it's drastically raised the scale of what's being built. Noise control engineers should join that revolution.

Transportation Noise

Comment: I'd like to bring up the noise barriers that are along the highways of Canada and the U.S.A. A new interstate highway was going into downtown Baltimore, but the Department of Transportation said it would cost too much money. Much later demand increased and now there are thousands of miles of noise barriers along U.S. and Canada highways. Subsequent studies showed a lot more noise, dBs, and people near highways than for airports. If it's planned in the beginning, you can absorb the cost and not even know it's there.

Comment: The comment about aircraft and highways is a good one. There has been great progress in the aviation area, and there is more emphasis on aircraft noise than there is on highway noise, but the number of people affected by aircraft noise is fairly small. So that's a problem. The problems that affect a large number of people are not getting addressed. Those that affect a small number of people have a lot of resources devoted to the problem.

Question: Is the road traffic noise problem more serious in Europe?

Answer: Yes, it is a problem for many more people. In Europe aircraft are responsible for 10 percent of the noise-annoyed population, rail 5 percent, and road noise 85 percent. Most people are annoyed by road noise.

Comment: The density of the population is important. For example, Israel's population is concentrated around Tel Aviv. Ben Gurion International Airport affects over 1 million people.

Comment: In Sweden in the early 90s the National Action Plan Against Noise made a limited study on the willingness to pay for better sound insulation. We asked two questions: 1) Are you willing to pay to be less annoyed by your neighbors? 2) Are you willing to pay not to annoy your neighbors? The responses were almost the same; there was an equal willingness to pay by people annoying the neighbors as being annoyed by the neighbors. It would be interesting to do the same study for road transportation noise. To what extent would drivers, car owners, be willing to pay to not be annoyed and be willing to pay to not annoy the neighborhood when driving?

SESSION 4: Codes, Practices, and Standards for Low-noise Machinery and Equipment

Panelists

- **Bob Hellweg,** Consultant, U.S.A., Session Chair
  Overview of standards and test codes
- **Jean Jacques,** INRS, France
  International machinery and product noise emission test standards and codes
- **Matt Nobile,** IBM, U.S.A.
  Product noise declarations for the general public
- **Patrick Kurtz,** BAUA, Germany
  Machinery and product noise emission limits and requirements
- **Mike Lucas,** Ingersoll-Rand, U.S.A.
  Limitations of current standards and test codes
- **Hans Jonasson,** SP, Sweden
  Future needs for standards and test codes for low-noise products, machinery, and equipment

Presentations

Bob Hellweg - Overview of standards and test codes for products and machinery

Standards and test codes can be broken into two categories: 1) Basic ISO standards for product noise emissions: product sound power level - ISO 3740 series; emission sound pressure level at the operator position - ISO 11200 series; and noise declarations - ISO 7574 and ISO 4871; and 2) machinery specific test code standards: for example ISO 7779 and ISO 9296 for information technology (IT) equipment and IEC 11600-11, -14 for wind turbines.

The users of standards and test codes

for products and machinery are the manufacturers who use them to test and report to customers; to governments on regulations, laws, and purchase specifications; and for use on eco-labels (ECMA-370 IT Eco Declaration, Blue Angel). However, the purchasers of products are the ultimate users of the results of the standards. The developers and writers should realize this, in my opinion, important fact.

The panelists in this session were given eight questions (in italics) and background for the questions (See Page 83 for background.). Following some questions are my responses.

1. *How can international test standards be more "user friendly"?*
2. *How can we involve consumers and the public in the ISO and IEC standards development process?*
3. *How do we ensure that manufacturers do not "cheat" on or misrepresent the noise declarations of their products?*

There is evidence that manufacturers have reported noise levels lower than those that should be obtained according to standards, resulting in unfair advantage over those manufacturers who follow the standards. Two examples of which I am personally aware:

The machine specific test code and declaration standard for IT equipment (ISO 7779 and ISO 9296) require testing of personal computers with fan speed control at temperatures of 23 ˚C ± 2 ˚C for products with fan speed control. Furthermore they also require testing of the emission sound pressure level L_{pA} at the front operator position, which approximately 0.5 m in front of a personal computer. I am aware of a European PC company that measures notebook computer noise at 20 ˚C during CPU operation and reports the emission sound pressure level at bystander position (which is about twice the distance from the computer as the front operator position).

Testing at an incorrect temperature results in fan speeds too low and A-weighted sound power levels and emission sound pressure levels are 2 to 5 dB (0.2 – 0.5 B) too low.

Testing at a microphone position that is twice as far as the correct position results in an emission sound pressure level L_{pA} that is approximately 6 dB too low.

Both result in the reporting of lower than required product sound data giving the false impression that their products are significantly quieter than their competition, which test properly. I have evidence that another PC company is also reporting PC bystander position L_{pA} in response to the first company claims.

In addition to the two previous examples, there are also possibilities of unintentional errors in the reporting of noise values to customers. Many people and organizations (with varying degrees of expertise) are involved in reporting noise values and their importance may be lost in the process:

Developers of basic standard (expertise) => Developers of machinery test codes (less expertise?) => Company engineer assigned to acoustics or external test lab engineer (less expertise) =>Test technician (still less expertise) =>Test report writer => Declaration determination from test data and analysis => Documentation writers => Sales and Marketing => end user.

4. *How can we ensure that test standards enable or encourage the application of technology without ambiguity and do not stifle innovation by acting as barriers to the implementation of technology? The International Standards must provide guidance for situations not considered by the standards.*
5. *What new measurement standards are needed? What current measurement standards need major revision to improve their usability?*
6. *How do we handle the confusion of consumers between sound power level and sound pressure level and the even more confusing use of the decibel as the unit of measure for both sound power level and sound pressure level?*

Why do acoustics standards use the same "metric" (decibels) for describing both product sound power level and emission and immission sound pressure level? No other technical product attribute uses the same unit to describe two different quantities as illustrated in the following table:

Energy	Product	Product Power	Human Response
Thermal	Heater	Watts	Temperature ˚C
Light	Light Bulb	Watts	Brightness, Lumens
Acoustic	Washing Machine	Power – dB	Pressure - dB

Based on the comparisons in the above table, consumers can easily understand the difference in light bulb power and brightness and in a heater power and the temperature in a room; in my opinion it is not surprising that consumers do not understand the acoustics of products. The IT solution is to express the metric for sound power levels in bels (instead of decibels) and keep the decibel to describe emission sound pressure level – thus consumers are no longer confused on whether the decibel value is sound power level or sound pressure level.

7. *In terms of product noise declarations (labels, tags, on-line information), actual numbers are important and useful for characterizing the noise emission levels, but how can we best get "comparative" noise-level information presented to a consumer on how one product compares to other products in the same family?*
8. *With respect to product noise declarations what about products that are loud enough that an additional concern (and perhaps the only concern) is as a "Noise Hazard" with the potential for hearing damage?*

Jean Jacques – International machinery and product noise emission test standards and codes: Standardized noise test codes for the measurement and declaration of noise emission values of machinery and equipment

Noise test codes are machinery-specific standards that specify all the information necessary for carrying out efficiently and under standardized conditions the determination by measurement of noise emission values of well identified families of machines. Based on ISO 12001 that fixes the rules for drafting of noise test codes, hundreds of noise test codes have been published during the recent years covering a large variety of machines and equipment. Some are ISO standards, many more are European standards backing the European regulation on machinery safety.

These are essential tools for the implementation of the international policy that consists, from noise emission data made available by machinery manufacturers to potential clients and through market forces, to encourage the putting on the market and purchase of low-noise machines.

The next step is to enforce the use of these noise test codes by machine manufacturers and the effective provision by them of good quality noise emission data to their potential clients.

Matt Nobile – Product declarations for the general public

How do we get noise level information to consumers so that they can make informed purchasing decisions? Our basic assumption is that we can increase consumer demand for quieter products if we start providing them with easy-to-understand noise information in the same way that we have increased consumer demand for more nutritious food by using nutrition labels, for more efficient appliances by using energy labels, and for more fuel-efficient cars by using mileage stickers.

First let's understand the terminology. There are three sub-classes of noise declarations: 1. Declarations published electronically, 2. Declarations published in print, and 3. Declarations published as physical labels. For electronic declarations, which we hope will be the primary approach, we have so-called "web declarations" that are marked up directly in html, along with pdf files and other online formats. For print declarations, which we hope will not be the format of choice because they are a headache to deal with, we are talking about noise declarations appearing in user manuals, spec sheets, flyers, and other hardcopy documents. And for physical labels, we have labels affixed to products, removable tags on products, or physical labels attached to the product or product packaging. They are all "declarations," and we prefer to use that term and reserve the word "label" for a physically-applied, stick-on label. However, the word "label" and the term "labeling" are very entrenched already so we may find ourselves using these terms even when the subject is an electronic noise declaration on a company website.

Although there are a few examples around the world of noise labels and noise declarations, most labels and declarations today are for energy. There are essentially three kinds of labels: 1. Information Labels and Declarations, which provide information, and give actual values; 2. Comparative Labels and Declarations, which show a product in relation to other products of the same type, and 3. Endorsement Labels and Declarations, which put a seal of approval or stamp of good merit on the product.

Last year we used the EU Energy Label to illustrate the benefits of providing consumers with product information particularly on a comparative basis — the EU Energy Label shows clearly how the rated product compares with similar products on the market. This label has been an overwhelming success in the 15 years or so since its inception. Energy consumption of appliances has decreased beyond expectations, so much so that additional categories like "A+" and "A++" have had to be added to the ratings because so many products now exceed the "best" performance envisioned when the labels were first introduced. We hope that the same thing will happen with product noise. Finally, our proposal from last year was to institute a "Noise Rating Tag" that looks a lot like the EU Energy Label, with its multi-colored bars, the A-G letter assignments, and the big, bold black arrow, only in terms of noise levels instead of energy consumption.

Although we thought it was a good proposal, there were problems with using the EU label format. Foremost among them was that it was prohibited by EU regulations to use any kind of label that could be confused with the Energy Label. But that was fortuitous because it forced the INCE Technical Committee on Product Noise Emissions to reevaluate our overall approach, and we found that there were other problems with using a label based on the EU label format. These included: (1) Problems with using letters.

Two products can have different letters and be only slightly different in level (44.9 dB vs 45.1 dB); (2) Confusion about cell "edges" in general (not all "C's" are the same); (3) Having both a declared number and letter can be confusing. Which is it, letter or number? (and why have both?); (4) Having a letter as part of a product rating prevents the range for this type of product from being updated in the future (e.g., EU label having to add categories like A+ and A++); (5) The "block size" in terms of dB for each letter would be different for different product types (i.e., the overall A-G range will be different); (6) The "length" of the colored lettered bars has no real meaning and adds confusion; (7) "Quieter" is at the top, a bit contrary to a "thermometer" type of scale; and finally (8) No sense of where the particular A-G range of noise being displayed fits into the overall range of noise levels.

Therefore, we are introducing a brand-new proposal that we think is much better than last year's proposal or anything else in the past. We note that engineers and the public want to know different things in terms of noise level information. While engineers may want to know the sound power level, sound pressure level, 1/3-octave band levels, discrete tone ratings, Sound Quality metrics, and other technical information, consumers really want to know just three things:

1. How loud is this product?
2. How loud is this product compared to similar products?
3. Can this product damage my hearing?

How loud is this washing machine? This is a question that we have not been addressing. Where in the overall range of noise levels does this product fall? And how loud is this washing machine compared to other washing machines? The answer to this question will drive their purchasing decisions and lead to quieter products. And finally, can this product damage my hearing? The public would like to have some sense from the number that is published whether or not this is a hazardous noise level.

Since it is nearly impossible to devise a product noise declaration with enough detail for engineers and practitioners yet simple enough for the general public to understand, we are proposing that various trade associations (such as the Information Technology industry) simply continue with their efforts to define and publish detailed product noise declarations and develop standards governing their content and use, but we define a new, simplified “Product Noise Rating” for the general public. The goal of the new “PNR” scheme would be to answer the three questions posed above.

The new PNR scheme will definitely contain a comparative element so that consumers can compare one product to another, but this doesn't really answer the fundamental question "How loud is it?" Even though I can learn that this desktop computer is quieter than another or that this hair dryer is the loudest on the market, how loud exactly is it? Can I even hear it? Will this annoy me? Do I need hearing protection?

What is needed to answer these questions in a way that the public can readily understand is a simple "Noise Scale" that shows the overall range of noise levels. This is the new and most important element of our proposal. The idea of a scale is not new as we are all familiar with the Richter Scale. There's a range of numbers on the scale, some simple language description of what these mean, and some examples. The public understands roughly how powerful an earthquake is by these simple one-number ratings. There are many other types of scales that have successfully presented technical information to the public in an easy-to-understand format.

Our proposal is to establish a Product Noise Rating (PNR) Scale for rating the noise levels of products for the public. It will be a numeric scale with simple-language descriptions of what the numbers mean and some examples. All interested parties and stakeholders will help us devise a consensus set of words and examples that define the scale, but the point is that we will have a simple PNR scale that consumers can understand. What, then, are the units on the PNR scale? There are no units! (It's a rating scale.) We feel that this will be most important in getting the public to embrace the use of this new PNR scheme. As we all know, they have seldom been receptive to the use of, or understanding of, the decibel (or the bel).

The use of a dimensionless scale is the primary element of our new proposal and the main difference from previous proposals. The second element involves how to present the PNR value to consumers. We propose to use a “noise-ometer” (like “speedometer”) icon. Of course, other icon approaches may be proposed (such as a “thermometer”); it is the information that is important and it should be uniform. The noise-ometer icon will display the overall range of PNR from 0 to 120. The big, bold arrow will clearly show where on the overall range the current product's rating value falls. This answers the first question, “How loud is this product?”

To answer the second question, “How loud is this product compared to similar products?” we can superimpose a simple range-of-levels segment along the overall scale that shows the range of PNRs for similar products. Again, this range of levels information is what we feel will finally drive down the noise levels of products as consumers start routinely looking for this comparative information.

Finally, for the third question “Can this product damage my hearing?” we propose adding a "red zone" for potentially hazardous levels (again in analogy with the red zone on a speedometer). Although the overall discussion of whether or not such Product Noise Ratings should be voluntary or mandatory is beyond the scope of this presentation, perhaps if the PNR is in the red zone, there might be a regulatory requirement to include an actual physical label or some kind of warning or safeguard on the product itself.

In terms of logistics of implementing such a Product Noise Rating scheme (scale plus icon), we anticipate that the following 5 groups, at least, will be involved:

1. INCE and the Technical Committee on Product Noise Emissions, which will write a "Recommended Practice" for use of PNR .
2. ANSI and ISO writing groups to turn that into a standard. There is a good precedent for this. The INCE Technical Committee on Information Technology Equipment, wrote a Recommended Practice for measuring the noise emissions of small air moving devices that was first turned into an ANSI standard and later an ISO standard. This is now the globally accepted way of measuring the noise emissions from small fans and blowers.
3. A suitable "agency" – too early to identify at this point – which will publish guidelines or regulations for use of the PNR based on the ANSI / ISO standard.
4. Trade associations, which will play a key role and decide on the PNR rules for their products guided by the agency guidelines and ANSI/ ISO Standard. These groups will also publish detailed noise declarations according to their own test codes and guidelines.
5. Non-Governmental Organizations (NGOs) will play a key role in advocating the use of PNR for all products, and publicizing quiet products. The overall goal, of course, is to quiet the world and not just to state the noise levels for the sake of stating noise levels, so NGOs are expected to play a key advocacy role.

In conclusion, we believe that if a Product Noise Rating for products became as available as energy labels or nutrition labels, then the public will start purchasing lower-noise products and even demanding them. Furthermore, consumers may be willing to justify spending a little more when they see the "arrow" closer to the quiet end of the range of similar products. When that happens, we manufacturers will get the message and be motivated to produce quieter products.

Patrick Kurtz – Machinery and product noise emission limits and requirements

Noise exposure at work places caused by machines is still the major reason for the most important occupational disease in Europe. Although European Directives explicitly require to reduce the noise emission of machines at source and to inform potential purchasers about the remaining risks by providing a noise emission declaration, machines have not significantly become quieter. New ideas are needed to foster the concept of using market forces in order to motivate machine manufacturers to design quieter machines and to provide reliable noise emission declarations. New approaches to better inform purchasers and to motivate them to apply the noise emission declarations are needed.

Regulations

In the EU the Machinery Directive (MD) was enacted in 1989 and updated with the latest version effective 29 December 2009. Its basic requirements are to reduce noise at source and provide a noise emission declaration. The declaration must include the A-weighted emission sound pressure level (SPL) and the peak C-weighted instantaneous sound pressure value at workstations and the A-weighted sound power level (PWL) emitted by the machinery. Besides the MD a second directive, "Outdoor"-Directive 2000/14/EC (OD), deals with the noise of equipment for use outdoors in the EU. The OD requires a label on the outer surface of the machine providing the guaranteed sound power level.

Noise Emission Declaration Formats
To allow a reliable declaration of noise emission values required by the MD, the European standard bodies were given a mandate from the European Commission to prepare noise test codes forming parts of so called C-standards (machinery safety standards). They rely on B-standards which describe the basic methods to determine both the A-weighted emission sound pressure level and the sound power level. Both quantities are characterizing the machine as a source of airborne noise and thus are independent from the measurement environment.

As the published noise emission values are used to allow the selection of quiet machines on the market, the operating, mounting, and installation conditions must be clearly defined. More than 750 noise test codes have been published for specific machines.

Noise Emission Declarations in Practice

Although there are many regulations and agreements requiring or allowing the information for potential purchasers about the noise generation of products, reliable noise emission declarations are rare. The reason for this is simple. First, the given noise emission values are not understood by the laymen because the quantities used, both sound pressure and sound power levels, are given in dB(A) and thus interpreted as having the same value. Second, there are no reference values given describing the state of the art of noise reduction for the specific type of machine. An assessment of the quality of the provided data is almost impossible, and noise emission declarations according to the MD are in many cases unreliable. Typically they are lacking correct references to standards; the emission values are measured for untypical operating conditions or use values copied from competitor´s declarations. Declarations may contain values which look nice to be particularly competitive, or are simply declaring emission values which are just below exposure limit values, thus pretending to be on the safe side.

On a very competitive market, 1 dB lower values may result in advantages which may motivate manufacturers to manipulate the values. As the market surveillance has so far ignored noise emission declarations as an item to be checked, the only solution for the customer is to inform the manufacturer that before purchase the declared noise emission values will be part of the contractually guaranteed characteristics of the product. Experience has shown that such information can lead to a rapid increase of the declared noise emission values before finally signing the contract.

Technical acoustical information seems to be too complicated to be understood by the purchaser of a machine or equipment and requires knowledge of acoustics. As for the purchaser, the production performance, the price, service, maintenance etc. are the key parameters defining the quality of a product; ergonomic or environmental aspects are ignored. In consequence, the noise emission of a machine or other equipment is neglected. This has a strong effect on the market because even those manufacturers producing quiet machines have no additional benefit for their efforts. Thus reducing noise by choosing quiet machines has not been very successful until now.

New Ideas to Promote Quiet Machines

To promote the purchase of quiet machinery or equipment a proposal has been made the European market surveillance advisory committee to check the present practice of noise emission declarations according to the respective requirements of the MD. A steering committee has been established. The intention is to collect a large number of noise emission declarations in the different member states and to check the quality of these noise emission declarations first by assessing the format of the declaration and second by a plausibility test concerning the declared values. A report will be written describing the present state of noise emission declarations in Europe and proposing ideas to improve the current unsatisfactory situation. This could result in better training for manufacturers as far as the application of measurement and declaration standards are concerned. The idea of establishing a European machine data base containing noise emission values could be revived with the consequence that purchasers would get easy access to comparable noise emission values and also to information about the state of the art of noise control for a specific type of machine.

In order to promote the use of emission values, it is essential to explicitly demonstrate to customers and occupational health and safety people how effective the purchase of quiet machines can be to reduce the noise exposure of workers. This can be achieved through more industry-specific publications using easily-understood language and showing simple examples for that industry. It will also be necessary to develop applicable and easy-to-use software which allows a rough estimate of the noise immission at workplaces based on noise emission values and room acoustic parameters for typical workplace environments.

However, there still remains the serious problem that dB(A) values are not understood as they do not always mean the same thing. The difference between emission, immission, and exposure values is a significant barrier for non-acousticians. To understand the related quantities like emission sound pressure level, equivalent continuous sound pressure level at the work station, and daily noise exposure level is difficult. Along with the sound power level, this often leads to complete misunderstandings between manufacturers and purchasers/users of machines. The approach from the IT industry to use the B(A) instead of the dB(A) for sound power level is not a solution. A more promising concept is the energy label which uses an easy-to-understand classification system, which people without technical backgrounds understand. However, that does not mean the classical noise emission declarations should be replaced. No, the solution is a combination of both— a presentation of correct technical emission values and the class system on one label. Although this idea is simple, its realization is complicated. There are three important questions to be answered:

- On what basis should the class limits be defined?
- How can a representative amount of noise emission values be achieved in order to define the class limits?
- How should the dynamic process of product development be handled to avoid outdated classifications?

Although these questions are not easy to answer, we should try to find answers. This idea has been adapted by many other parties interested in the topic of labeling. European gardening equipment manufacturers seem to be interested, and the IT industry is likely to develop further their approach to declaring noise emission values. Presently the Federal Institute for Occupational Safety and Health (BAuA) in Dortmund is funding a project with the aim of establishing such a classification system for office machines. Cooperation with interested parties in the IT industry is in progress.

Conclusions

The application of noise emission values to reduce the noise exposure at workplaces is not yet very successful. One might call it a failure, although regulations on noise declarations and standards do exist. Moreover, employers are obliged to use these emission values when buying new machines in order to buy comparatively quiet ones. In consequence, it is time to take a new approach to be successful. Besides better information for all parties concerned, it may be necessary to develop a new format for the declaration of the classification system similar to the European energy labeling for house hold appliances.

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Mike Lucas – Limitations of current standards and test codes

Test codes are not perfect. Test codes are written for a wide audience of users where problems with the interpretation or implementation of the code are not realized until the test code is fielded. It is no surprise that international standards can be easily misinterpreted and abused to gain a product market advantage. The creators of these standards need to be always vigilant, they need to be always listening to feedback from their users, and they need to be revising the standards based on input from the user community. Sometimes revisions to the standards are not enough and laws are required to ensure the true intended purpose of the standard is achieved by the standards organization.

In the past 10 years the International Standard Organization has fielded a large number of acoustical standards that have been adapted in some cases by whole industries and in other cases by individual manufacturers. Many times test codes are referenced in the engineering product literature. The declared value and the referenced standard are used by consumers when choosing between one product manufacturer and another. This puts pressure on the manufacturer to achieve the lowest noise level possible to gain market advantage. And here lies the crux to the problem.

In acoustics there are many techniques for measuring sound power of a product. Some of these techniques are more robust and less likely to give false readings than others. Depending on the size of the product or its installed running condition, some measurement techniques are not at all applicable to the given situation. All of these issues are taken into consideration by the creators of the measurement standards. It is however unfortunate that some of these measurement techniques can be abused to achieve a low product reading.

It is the author's opinion that acoustic intensity is one of these measurement techniques that can be abused and should be avoided as a method for determining the declared value of a product. Intensity should only be used when no other method can be reasonably applied. There are many situations where intensity can give false readings, for example areas where large cooling vents expose the intensity probe to high velocities of heated air. Other situations are areas where the machine can not be practically scanned because of its size or proximity to reflecting surfaces.

How can international test standards be more "user friendly"? First, the standards should be simple to use and can be easily understood by users worldwide. The standard needs to be easily understood by users that are not necessarily trained in acoustics. Second, the instrumentation required by the standard should be readily available and not too expensive. Some manufacturers have small discretionary budgets limiting the amount of resources they can allocate to noise testing. A type 2 sound level meter is the most affordable acoustic instrument that is available worldwide. Finally, the standard should take into consideration large machinery that has a package cooling system. Often times the package cooling system is the greatest contributor to the product noise and is sometimes the most difficult to measure accurately.

How do we ensure that manufacturers do not "cheat" on or misrepresent the noise declarations of their products? On the whole, most manufacturers do not deliberately cheat, but they may identify weaknesses in the standard that can lead to lower measured noise levels. ISO-3744 describes the measurement of sound power using a pressure microphone. ISO-3744 is probably the most robust of the noise standards and should be used whenever possible to measure a declared value of a product. ISO9614-1 and 9614-2 are two acoustic intensity standards. One standard describes the measurement of sound power by making measurements at discrete points and the other describes the measurement of sound power using the acoustic intensity scanning technique. Both of these techniques are accurate methods for measuring sound power when performed by a trained expert in the use of acoustic intensity, but without the proper training both of these techniques can easily give false readings. Another problem with either technique is the inability to make any kind of accurate measurement near a package cooling system. As a result, many users of acoustic intensity tend to scan around the package cooling system, thereby not including in the measurement one of the major contributors to the product noise level.

How can we ensure that test standards enable or encourage the application of technology without ambiguity and do not stifle innovation by acting as barriers to the implementation of technology? The ultimate goal is to lower the noise levels of consumer products. To achieve this goal an environment needs to exist where all manufacturers are fairly competing among themselves. A simply analogy is a speed limit sign that has no enforcement. Drivers will naturally ignore the sign until they learn otherwise that there is a fine for not following the speed limit. Standardized product labeling and enforcement will lead to new innovation and technologies that will lower product noise levels. Standards can be used to promote competition between manufacturers when they know that their competitor is following the same system of rules. If the standards are adapted worldwide, then developing nations will be encouraged to adapt the same standards; thereby becoming a partner to the world community in developing new technologies that will lower a product's noise level.

Hans Jonasson – Future needs for standards and test codes for low-noise products, machinery, and equipment

The paper focused on answering the following three questions prepared by the organizers:

1. How can international test standards be more "user friendly"?
2. How can we involve consumers and the public in the ISO and IEC standards development process?
3. What new measurement standards are needed? What current measurement standards need major revision to improve their usability?

Examples on current problems behind Q1 are:

- The standards spend much space and effort on problems that do not occur very often;
- Many equations, such as some new ones on measurement uncertainty, look terrifying, and tend to make people hostile to the standard;
- The language is ”ISO English,” that is it is often not easily understandable.

Some ways to improve the situation could be

- Make simplified versions of the most important standards. Another way to do this could be to exploit the fact that to-day most standards are delivered electronically. This means that the text could be held short and extra information, if needed, is given using links to additional files.
- Include preprogrammed spreadsheets with the standard (See ISO 9612 for example) where the only input is measured values and all calculations are programmed. This is particularly important for the new methods to determine measurement uncertainty.
- Create incentives to make standards simpler (standards writers tend to be conservative and may need some ”help” to carry out desirable improvements).
- Use more pictures and less text.

Q2 is a difficult question but the following actions could be a good starting point:

- A first prerequisite is that the standards are understandable by interested parties, see Q1.
- Make it cheaper (not so easy!) to participate in the standardization process. In many countries you have to pay for possibility to influence standards.
- Inform interested parties about current projects and provide the possibility to give feedback to the standardizers.
- Distribute all ISO/DIS to interested parties for additional comments to be considered by the WGs.

Q3 on the need for new standards is too wide to be answered in detail but some examples are the following:

- For the basic sound power standards systematic errors have to be dealt with. Two such known errors are box-shaped measurement surfaces when determining sound power levels in an essentially free field above a reflecting plane and the erroneous assumption that the sound pressure level always increases by 3 dB when adding the reflecting plane (Depending on machine and frequency the increase may be up to 6 dB)
- Provide alternative measures for low noise levels, the A-weighted sound power level may not always be the best solution.
- Improve methods to measure narrow band noise in semi reverberant environments in situ.
- Sound power of multiple sources (cars, trucks, snowmobiles, etc.)
- Allow for different impedance surfaces, such as asphalt versus grassland.
- Prediction in the field from laboratory measurements where we need a standard describing in detail how we can use measurement values from the laboratory to estimate the sound pressure level at the operator in a field installation.

Finally, it was concluded that vast improvements have been achieved in international standardization as a result of the still ongoing globalization process. However, as focus has been on filling gaps in current standards, not so much has been achieved in improving the user friendliness of the standards. Although there is still need for new standards it would be beneficial for the future use of the standards if more effort was devoted to simplify the practical use of the standards.

Discussion

Component Sound Levels

Question: Should component manufacturers be forced to declare sound levels to the public?

Answer: For example, with component manufacturers we're talking about fans that are going into other products. I'm not sure that an individual needs this specific information on the noise levels of individual components that go into the end-use product.

Comment: There are other problems which need to be solved, for instance, hydraulic pump descriptors. To describe a hydraulic pump in the sense of a source acoustically is rather complicated. We are only talking here about airborne noise. But what about describing a fluid-borne noise source? I think we are still lacking the right descriptors to do that. About 10-15 years ago we tried to have Working Group 22 define a descriptor describing this structure-borne noise source. We were unable to find a unique descriptor for the different ways in which waves are generated. As long as we haven't a solution for that, it's simply not possible to find an easy way to describe a component and its contribution to the overall sound of a machine.

Question: When you have heavy equipment such as your company makes, there is a big problem specifying how much noise it makes because it depends highly not only on the operating conditions but by how it's installed. How the flexible connections are between your equipment and other parts of the plant that you have no control over. In other words, the installed noise can be radically different than was expected because of the poor or excellent installation. How do you deal with that?

Answer: That's an excellent question. In particular with centrifugal machines, most of the noise occurs after the machine—at the flange point—somewhere down there you've got a valve, and that valve you've got to close down so you can get the pressure you want to get. So all that noise is going out of that valve. Well that's not part of the reported noise level of the machine. In addition, centrifugal machines can be bigger than this room. So what do you do? How do you measure it? And we don't have a good way to do that. Another U.S. company is using some techniques that I think are really solid. One of those is a standard that uses an accelerometer, and what you do is go around with an accelerometer and measure the vibration, the structural radiation of that machine. I have been playing around with that quite a bit and you'd be surprised at how accurate that technique is because not only can you identify the noise sources, but you're isolating just the radiated sound from the machine and you're not considering these other sources. It's kind of risky to use that standard because you can get different numbers if you're not careful, but it's certainly a good way to quantify the sound power.

Uncertainty Data for Noise Test Codes

Question: What is the interest of the users of noise test codes to have well-defined uncertainty information included?

Answer: The interest of the user depends on how to check the declared data. If the measured value is reduced by the uncertainty, they are not interested in the precise uncertainty. The users take the upper limit given by the basic documents that includes all possible families of machines. They are not interested in establishing machinery-specific realistic values for their machinery. But if we do not allow subtraction of these values, then they are interested in more precise measurements.

Comment: When we talk to manufacturers, we are facing the situation that many of them have no idea about uncertainty with their own products. The tendency in this case is to simply refer to the values made available in the basic standards. I suspect those manufacturers who have that information don't want to share such information.

Involvement with Standards Development

Question: To involve stakeholders more, why can't the objective and overview of standards be supplied allowing for comment including time taken for measurements and example-simplified spreadsheets?

Answer: As I said before, ISO is a very conservative and difficult organization to change. But if we start trying, I'm sure that sooner or later it will be possible to make simplifications. This is a great opportunity to start thinking about it because it's quite clear that in the past we have focused on solving our technical problems and making the standards more accurate. Perhaps the focus could be changed to make the standards more user-friendly. We have to find a solution to that. Existing procedures of ISO are extremely strict, and one is not allowed to make any changes. Thus changes may take some time to achieve.

Comment: The unfortunate situation is that when we start to revise the standards, we have the feeling that no additional experience is gained. We are sitting with the same people we have seen five or six years earlier.

Comment: What is necessary is for the machinery-specific people to write a noise test code to clarify the advantage of having realistic lower values for their machinery instead of the limit values given by the basic standards.

Comment: At the moment getting all possible stakeholders involved is a major issue for the whole standardization system throughout the world. It is not specific to acoustics; it's a very general problem. The situation is not getting better; it's getting worse. Because we are now past the era when we had many experts around the table—ISO staff to deal with problems, many manufacturers, and authorities. Now we get fewer and fewer experts participating. There are financial problems all over the world. The situation is not improving; it's more and more difficult to get the stakeholders involved. In France efforts are made to get consumers and trade union representatives to participate, and there is some progress in this direction. Trade unions are important because you will get feedback from the people who are actually using the machines everyday in their work. These people normally are not involved, so get their opinion about the problems they have met when using the machine.

Comment: One of the major reasons is that nowadays we depend more or less on the economic aspect. It must be shown that quiet machines will provide a benefit for the company and will bring more income for the company. If we don't achieve this, we will have no improvement at all. We have serious problems in getting representatives from machine manufacturers into the European standardization groups. It's unbelievable—you sit together with people who are in a position that does not allow them to discuss the technical aspects. How can you then prepare a good standard? It's almost impossible. Sometimes I run into a situation where proposals are written based on our knowledge but with the feeling that we're developing the measurement methods for a type of machine about which we don't know enough.

Question: Why is it so hard to get feedback when revising standards?

Answer: It is hard to get feedback from people who don't want to talk to you. I keep suggesting that on the first page of every standard a flashing light giving an e-mail address where the user of the standard can react and submit ideas in his experience with the use of the standard. This is possibly a way for many people who are using standards to understand that standards are living documents that are revised and they can contribute to the revision by letting the revisers know what they have done with the standard. How they like it; how they don't like it.

Question: How can we use the Internet to encourage the public to contribute towards the international standards?

Answer: That sounds like a good idea. It is a bit problematic, but there are traditional procedures of standardization. Hopefully it will be possible to get an agreement so we can make standardization more transparent than it is today. Today there is a rather limited way of developing standards. There may be four or five people in the world who seriously study the standards and are capable of correcting them.

Comment: The key questions for this discussion are: What is the state of the technology? How do we make the standards usable to help create a quieter environment?

Comment: Those who really can contribute to standards are probably here in this room. However, we also need to find a number of individuals in five or six different countries who are willing to act politically to get something to happen. It is easier to find countries where this is impossible, but what we are looking for is countries where we can get the policymakers high up in the hierarchy who can help us to drive the noise issue further internationally.

Enforcing Product Noise Requirements

Question: How do we require or enforce product noise requirements? Is it to require or enforce per country or region a viable, efficient approach? How do we globally harmonize these?

Answer: Let's go back and look at why was ISO successful. There were a number of standards out there, and a number of different standards organizations for each of the different societies. Those standards were generating revenue for the different societies. Then ISO came along which is not really an international standard but a European standard because every European country gets a vote—Luxembourg gets 1 vote, the United States gets 1 vote, China gets 1 vote, and India gets 1 vote. So what that did was give ISO more leverage in terms of how the standard was going to be corrected and designed. In addition, many of the meetings were over in Europe so a lot of American manufacturers were not able to go just because of travel costs. But ISO did a very good job. As a manufacturer worldwide my company was forced to adhere to the rules, and we scrapped our standards—there were a number of them—and went along with the ISO standards. In addition, American standards were worded so that they would be recognized as ISO standards. That's why I feel that if we're going to have enforcement, ISO is going to have to take the lead again. America is not in a position to take the lead given the political problems that are going on and that there's not going to be complete agreement among all the companies. The American companies will push back. Another thing is that we don't have a densely populated nation like Europe does; and so noise is certainly more important to the Europeans than it is in America.

Product Noise Labeling

Question: Do you have enough stakeholders involved with your committee for their input in the development of your revised labeling proposal?

Answer: Yes and no. The keyword there is the development of the proposal. We have a pretty good cross-section on the technical committee itself—there are about 35 involved INCE members. To get final approval for whatever we are going forward with we need a much broader group of stakeholders. Getting back to the word *development*, we have enough representation on the technical committee to produce a draft, and that's our immediate goal—to produce a recommended practice, a draft that will then go to a much broader range of respondents and stakeholders to get the final version.

There are stakeholders and there are stakeholders. The question was directed at my proposal and the key stakeholders of my proposal, the public, want a product noise range for the public. We have ignored them in the past for various reasons, and it's not an identifiable group that we can approach. They do not attend our meetings, they're not on the technical committees; but that is changing. There are more and more advocacy groups out there such as the Noise Pollution Clearinghouse. It would be a key stakeholder. Consumers Union in Westchester is another key representative of the consumers. They're not part of our meetings, but groups such as these are the stakeholders.

Comment: I certainly encourage this plan, but I have more of a cynical view of this and that is that I feel ISO needs to take the lead because ISO is the one that started this. The reason is that what happened with ISO, at least in the compressor industry is that the standard came down; we were forced to follow because we sell products worldwide. Other countries around the world began to adapt the standard, and that is why we have a standard now today that we all follow. Prior to that we had a number of different standards that we used worldwide and, depending on the country, which standard we chose to use. So if ISO were to develop a standard that would incorporate labeling and penalties, then I think that we have a good start.

Question: If there are limits on products, who cares if there are informative numbers for levels that are less than the limit? Why regulate if there is no hazard?

Answer: The situation mentioned with the European directives in setting up limit values for very noisy machines is a good idea. The problem was that too many lobbyists interacted, and it weakened the whole preparation of the directive with the consequence of the unstable situation we now have. The consequence is that nobody really deals with these numbers anymore. Even the state officials are not dealing with them. A proposal was made for the European Commission to have joint action on market surveillance. We agreed to have this action only for the machinery directive, but only that we check the plausibility of the data. That means not measuring what has been declared, but checking. This is a problem for the stakeholders in market surveillance in Europe. So what happens if the declarations are wrong? Do we have to give penalties for that? No, what we want to have is a good picture of the situation. With this argument it is only possible to run this joint action on market surveillance. It's really the state's fault that nobody controls it. It's like hoping the market will solve the problem, and the market doesn't solve the problem because nobody is really interested. We must find a way to make consumers, customers, and factories aware of how to use these values. Limit values should be used by all companies, maybe slightly changed, but that's something which is necessary. If we don't realize this broad use, we will never finalize what a good declaration is with reliable values or whether they are limit values or not.

Answer: If it's not hazardous, why regulate it? There are two sides to this. The easy answer is, let's not regulate it. If they do not pose a noise hazard, but are only quality-of-life effects, I'm for letting the market get the information to the consumer. Having said that, I realize there is another side to this. What I've used in the past as an example on how getting information out there can really help drive down noise levels, is the EU label on energy efficiency. It worked, and it's continuing to work, and it is legislated. So it is mandatory to have that label in Europe. Once that label is out there, the efficiency increases. But I think the jury is still out on whether or not it is because this is legislated or because the information was made available. I think it was the latter. Once the information was out there, the efficiencies went up. If we can get the information out there without legislation or regulation, I think the noise levels will come down. But if we get to the point where consumers routinely see this noise information available, are routinely using it and manufacturers and trade associations are still not publishing the noise information, we can revisit the whole issue of making it mandatory for lower-noise products.

Comment: I would like to see quieter products manufactured and purchased. However, I don't know if that is a goal of labeling that we'll have quieter products purchased. I would like to think we let the consumers have the option to purchase quieter products if they want to because consumers don't have that option today. If we do make available information on whether the products are quiet, the market will drive it; and you will see quieter products as the result.

Question: Product noise rating is the way forward. Let's set up an international collaboration to bring it through and put pressure on manufacturers worldwide to make good quality noise emission data available publicly. Is that feasible?

Answer: The proposal which Matt Nobile presented today is a good step in the right direction. In my institution I'm responsible for customer help and guidelines, and this is one of the strategic aims of the Federal Institute of Occupational Safety and Health. We have a chance on special kinds of machines to establish something which could be taken as an example for other product types. It is much easier to establish guidelines in the IT industry than it is for concrete breakers. This may be a good example of how other manufacturers can be convinced to have the same solution or at least a comparable one.

Comment: There are many European product specific test codes which you can use if you want to check products and the labeling at the national level. In Europe, each nation is responsible for product control and they can do what they want to do. The problem is that they don't want to carry out checking of noise levels because it costs money. Occasionally we have done it in Sweden for, for instance, toy guns because the consumer agency has been very active in this respect. Probably they wouldn't care so much about these compressors.

Question: The need for labeling and the way to do it should strongly depend on the number of products put on the market in each category. There may be ten very specific machines of one type. There may be 10,000 industrial compressors; there may be 10 million laptops. How does one handle that?

Answer: There's an implicit assumption that the need depends on the market size. I'm not sure I totally agree with that. We've been talking about a product as if we all know what a product is, but in our technical committee there's a task group which is trying to define what we mean by a product that will bear the simplified product noise rating for the consumer. There are products where this information is required, but for planners of data centers, factories, or large compressors, we're not anticipating the use of a simplified product noise rating for this kind of equipment. There are different needs for the different products. We have to differentiate the end purpose of the equipment in terms of the importance of the "label." For consumer products where we are talking about millions of products, there is a need; and the need should be for the simplified label that I've been discussing. On the other hand, even if it's a very small market of ten or a dozen large, noisy compressors that are going into a sensitive area, or there's one planner who's building one factory; the need for accurate information on those products even for a small market is just as important.

Cheating on Noise Declarations

Question: Where is the published evidence that manufacturers are "cheating" on noise declarations? We will put quotes around "cheating" meaning that they're providing incorrect information on the noise declarations.

Answer: There is no published evidence. At our U.S. company when we start a new line of products, we do a competitive evaluation. We'll buy a vendor's machine, and sometimes we have to buy these machines under the radar so that they don't know what we're buying. We set these machines up and measure them. We measure them for power, capacity; and we measure them dimensionally. We have surveys. We have people come in and they do scorecard evaluations on these, and we find the weaknesses and the strengths. One of the things that we measure is noise, and that is where "cheating" comes up. I don't know how to respond when our marketing department says that the machine is 78 dB and they're advertising 74. Marketing asks me if we can make a machine at 74 dB, and I say yes, but it's going to cost you and it's going to add $1000 to the price of the machine. So it's a struggle. That's why I feel that it's very important to have honest numbers out there.

Comment: On a popular website it says the measuring position for a PC is about one meter away from the PC; the standard says that you test at a half a meter away. As acousticians we all know that means a 6 dB lowering of the sound pressure levels. There's evidence of cheating there—presenting incorrect values. It is out there, but what can be done? Those in this room who might work for a manufacturer don't do that, but we are aware of other companies who do. An analogy might be the Tour de France. We'd all like to think that the riders are doing this on their own, but we very well know that many of the champions and top riders have used a form of enhancing drugs that shouldn't be used. We'd like to think they're not doing that, but there are some who do.

Question: How are manufacturers able to cheat using intensity in ways that they can't using pressure?

Answer: As I pointed out, whenever you put an enclosure around something you have two openings—an intake and a discharge. With acoustic intensity it's well known if you get over 3 meters per second, you can certainly influence the level and you can make it much higher than what it's supposed to be. What I suspect some people do is just scan around the machine and ignore the vent totally. Just measure the radiation of the structure. Because as soon as we go over that hot air, your microphones are going to get very hot, they're going to operate out of their specified ranges, and you've got air blowing over them; and that's a critical problem with intensity. That's why when we had the ISO 2151 committee meetings, I sat in on those committee meetings. A Swedish company was there, and they like to use intensity. I argued that we needed to include the hemispherical technique which they finally did because the beauty of the hemispherical method is that you can put your microphone four meters away so that you're far enough away from that air you don't have any influence.

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Conference Calendar

Below is a list of congresses and conferences sponsored by International INCE and INCE/USA. A list of all known conferences related to noise can be found by going to the International INCE page on the Internet, www.i-ince.org.

2011 July 25-27
NOISE-CON 11
Portland, Oregon
Contact:
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Amy Herron, Conference Coordinator
INCE/USA Business Office
9100 Purdue Road. Suite 200
Indianapolis, IN 46268-3165
Telephone: +1 317 735 4063
E-mail: ibo@inceusa.org
http://www.inceusa.org/nc11

2011 September 4-7
INTER-NOISE 11
Osaka, Japan
Contact: INCE/Japan
c/o Kobayasi Institute of Physical Research
3-20-41 Higashimotomachi, Kokubunji
Tokyo 185-0022
Facsimile: +81 42 327 3847
e-mail: office@ince-j.or.jp
home page: http://www.internoise2011.com

2012 August 12-15
INTER-NOISE 12
New York City, USA
Contact:
Institute of Noise Control Engineering-USA
Amy Herron, Conference Coordinator
INCE/USA Business Office
9100 Purdue Road. Suite 200
Indianapolis, IN 46268-3165
Telephone: +1 317 735 4063
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Directory of Noise Control Services

Information on listings in the Directory of Noise Control Services is available from the INCE/USA Business Office, 9100 Purdue Road, Suite 200, Indianapolis, IN 46268-3165. Telephone: +1 317 735 4063: e-mail: ibo@inceusa.org. The price is USD 400 for 4 insertions.

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Mark your calendar and plan to participate!

NOISE-CON 2011

Portland, Oregon
July 25 – 27, 2011

The 27th annual conference of the Institute of Noise Control Engineering, NOISE-CON 2011, will run concurrently with the summer meeting of the Transportation Research Board, Committee on Transportation-Related Noise and Vibration (ADC40) on Monday through Wednesday (25-27 July, 2011). This conference is joining the overlapping transportation noise and vibration interest of the two organizations in Portland, Oregon to take advantage of the strong public interest and readily accessible public transportation project sites currently found in the Pacific Northwest. The technical program for the joint conference will provide an opportunity for public and private organizations to share technical information on noise and vibration topics associated with high speed rail, light rail systems, highway surface and tire noise and aircraft noise to name a few.

The INCE/USA Page at the Atlas Bookstore

www.atlasbooks.com/marktplc/00726.htm

INTER-NOISE 06 Proceedings

This searchable CD-ROM contains the 662 papers presented at INTER-NOISE 06, the 2006 Congress and Exposition on Noise Control Engineering. This, the 35th in a series of international congresses on noise control engineering was held held in Honolulu,Hawaii, USA on December 3-6, 2006. The theme of the congress was “Engineering a Quieter World.”

The technical topics covered at INTER-NOISE 06 included:

- Aircraft and Airport Noise Control
- Community Noise
- Fan noise and aeroacoustics
- Highway, automobile and heavy vehicle noise
- Machinery noise
- Noise policy
- Product noise emissions
- Sound quality.

The NOISE-CON 05 Proceedings Archive (1996-2005)

This searchable CD-ROM contains 198 papers presented at the joint NOISE-CON 05/ASA 150th meeting as well as 749 papers from the NOISE-CON conferences held in 1996, 1997, 1998, 2000, 2001, 2003, and 2004 as well as the papers from the Sound Quality Symposia held in 1998 and 2002. All papers are PDF files.

Several papers are taken from sessions organized by the Noise, Architectural Acoustics and Structural Acoustics Technical committees for this 150th ASA meeting. The three plenary lectures related to noise and its impact on the environment are included. Also included are papers in one or more organized sessions in the areas of aircraft noise, tire/pavement noise, and hospital noise.

INTER-NOISE 09 CD-ROM

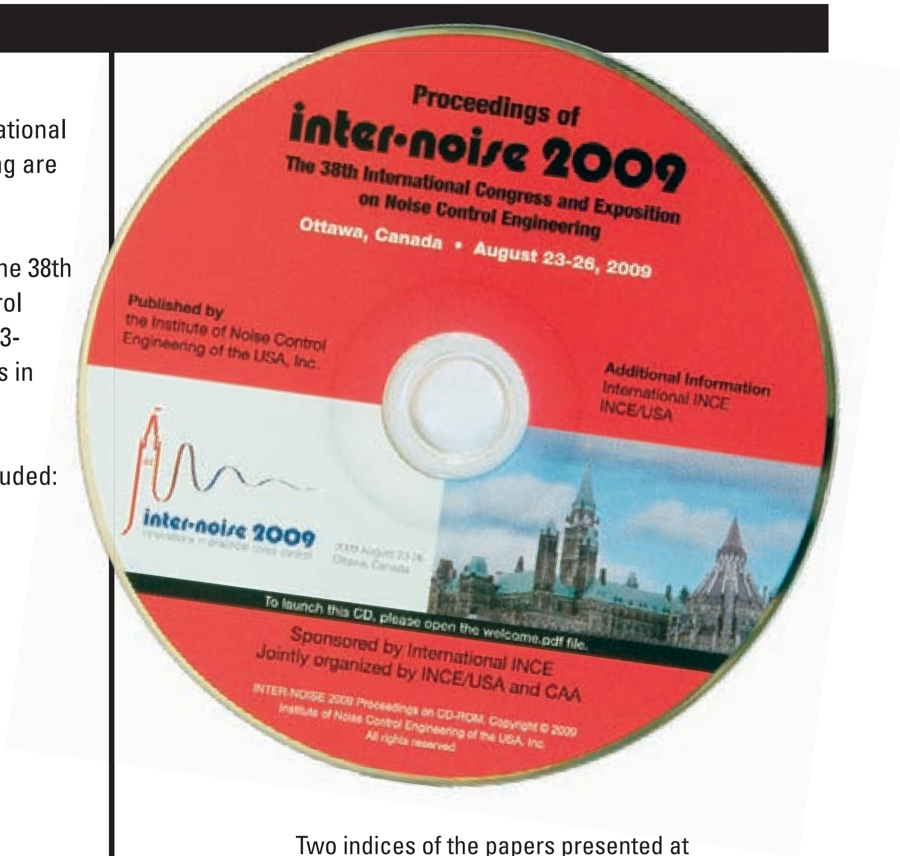
The Proceedings of INTER-NOISE 09, the 2009 International Congress and Exposition on Noise Control Engineering are now available on CD-ROM.

This searchable CD-ROM contains 627 papers This, the 38th in a series of international congresses on noise control engineering was held in Ottawa, Canada on August 23-26, 2009. The theme of the congress was "Innovations in Practical Noise Control."

The technical topics covered at INTER-NOISE 09 included:

- Aircraft and Airport Noise Control
- Active Noise and Vibration Control
- Building Acoustics
- Community Noise
- Barriers
- Fan noise and aeroacoustics
- Highway, automobile and heavy vehicle noise
- Machinery noise
- Noise policy
- Product noise emissions
- Railway noise
- Sound quality.

These papers are a valuable resource of information on noise control engineering that will be of interest to engineers in industry, acoustical consultants, researchers, government workers, and the academic community.



Two indices of the papers presented at INTER-NOISE 09 are available on the Internet:

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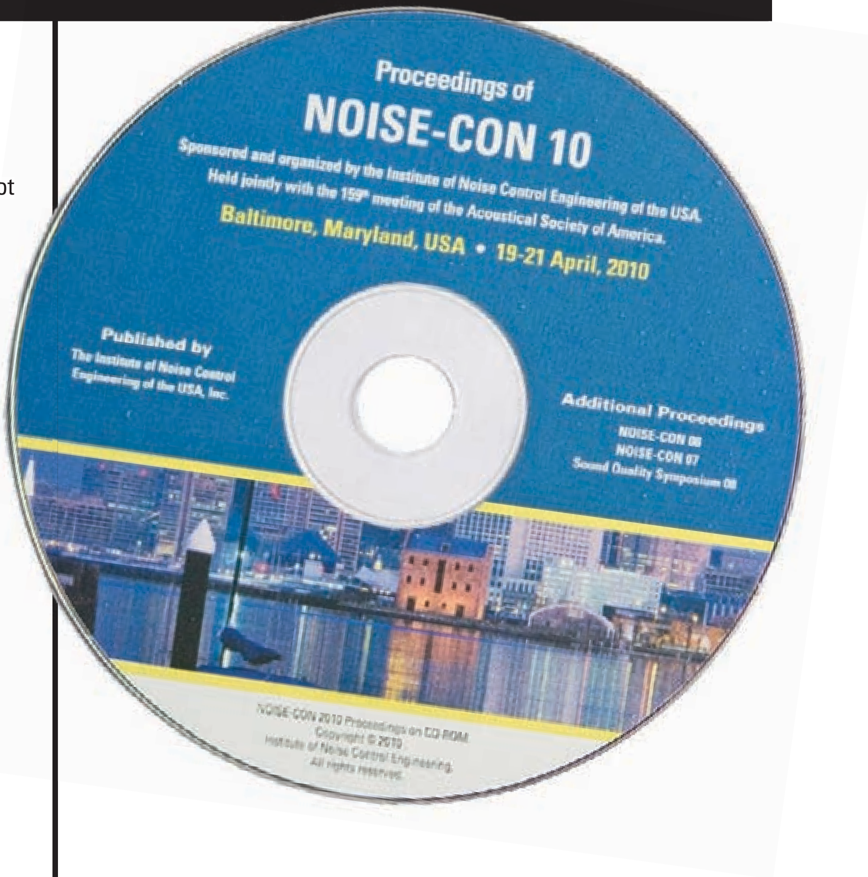
NOISE-CON 10 CD-ROM

This searchable CD-ROM contains PDF files of the 198 papers presented at NOISE-CON 10, the 2010 National Conference on Noise Control Engineering. NOISE-CON 10 was held jointly with the Acoustical Society of America on 19-21 April 2010 in the Marriot Waterfront Hotel in Baltimore, Maryland. This CD does not contain the papers presented as ASA contributions.

In NOISE-CON 10, there were 24 technical sessions:

- Rocket Noise Environments
- 15 papers Noise Control in Complex and Urban Environments
- 11 papers Ventilation, Fan and Duct Noise Control
- 21 papers Military Noise Environments
- 16 papers Case History, Application and Integration of Architectural Acoustics in Building Modeling
- 14 papers Materials for Noise Control
- Manufacturer Presentations
- 10 papers Building Design and Construction for Effective Acoustic Performance
- 10 papers Experimental Techniques
- 10 papers Construction Noise
- 14 papers Information Technology Noise
- 10 papers Aircraft Interior Noise

This CD also contains Proceedings from NOISE-CON 08, NOISE-CON 07 and papers on sound quality presented as SQS08, the 2008 Sound Quality Symposium. This CD-ROM supplements the NOISE-CON 05 CD-ROM which contains all of the papers published in NOISE-CON Proceedings from 1996 through 2005. These papers are a valuable resource of information on noise control engineering that will be of interest to engineers in industry, acoustical consultants, researchers, government workers, and the academic community.



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