The Importance of Engineering Acoustics
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1 Why dealing with acoustics ?

In this section you will find brief description of the importance of acoustics as discipline, it main applications and its relation to our daily life at work and at home.

1.1 Introduction

Acoustics is an own discipline with a strong interdisciplinary character. Engineers who are experts in acoustics will find their tasks in a wide area of applications such as aero acoustics, vehicle acoustics, product development, community noise, architectural acoustics, psychology, virtual reality applications, telecommunication etc.. They will also support other professions, such as medical doctors, psychologists, biologists, oceanographers, designer, engineers in different areas of mechanics and so forth. Figure 1 is an attempt to illustrate the area from the core – fundamental physical acoustics – to its applications and relations to a range of disciplines.

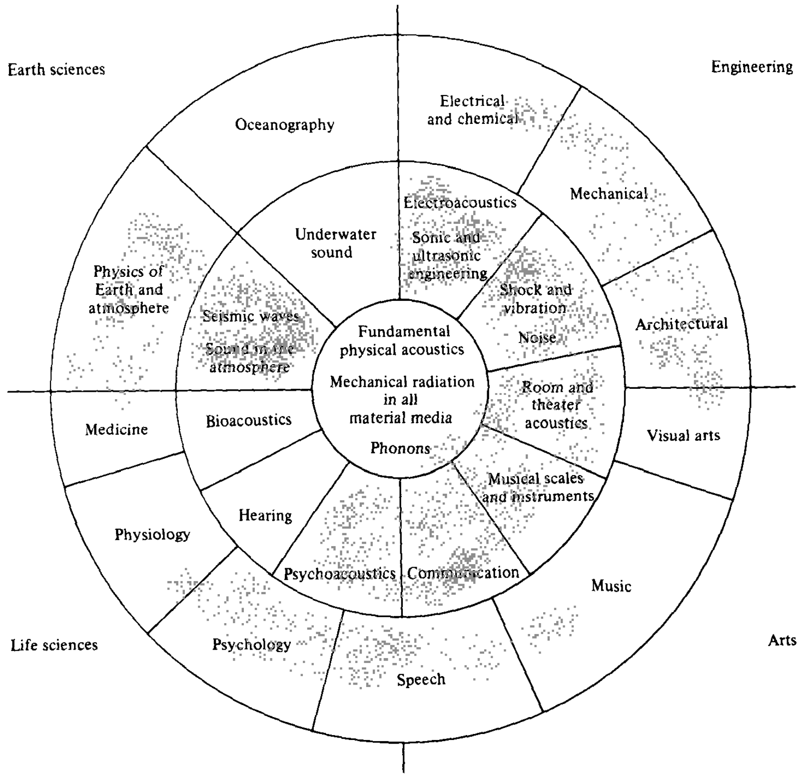

Figure 1 Acoustics and its relation to other disciplines and applications (shadowed area indicates the field of activity at the Department of Applied Acoustics, Chalmers University of Technology)

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Knowledge in acoustics is essential to promote the creation of both products and environments, which are reasonably free from harmful and/or intruding noise and vibrations. In contrary they should demonstrate vibration and sound quality (or let say an acoustic comfort) which supports and enhance the functioning of the product or environment. In other words; acoustics is a of great importance for a competitive products and for a sustainable development of technologies in our society.

Courses given by the department of Applied acoustics at Chalmers cover important parts of the areas sound and vibration. Within this area we have among others courses in audio technology, electroacoustics, measurement techniques, design of silent products, structure-borne sound and active control of sound and vibrations. More information concerning our international MSc programme "Sound and Vibration" is available under www.ta.chalmers.se.
The material in the course "Noise control mengineering" covers basics in acoustics and some applied areas of importance for engineers who later might work with questions related to sound and vibration..

Smoke and noise were the classical symbols for industrial progress and power. The smoke is to a great extent eliminated, but the noise remains. Noise is a difficult pollution, both in outdoor and indoor environments. The fundamental reason is that we depend in our society on so many different machines and tools and most of them are quite too noisy. This is true for aircraft, road vehicles, ventilation systems in buildings, outboard engines, lawn mowers, household machines, industrial machines and tools, etc. To make these machines and tools quieter and free of vibrations is mainly a task for the mechanical engineer. It is a demanding task. It is much easier to make a machine or a car that runs faster than to make it quieter (Manfred Heckl in one of his lectures). The tasks related to acoustics also involve comfort and what we call sound and vibration quality. The product must have the right sound to satisfy the customer! This has become increasingly important especially for cars. Therefore, acoustics and noise control is a very important work area in the automotive industry and knowledge in acoustics needs to be an integrated part of mechanical engineering.

It is often said that the most effective method to solve environmental problems is the stop the pollution at the source. If we then take the present day situation it is a very long way to go until all machines and tools are so quiet that their noise pollution will not cause any problems in their environments. To give a rough figure, it would demand a noise reduction of each individual source of the order of 10 – 30 dB if all the problems were to be solved solely by reduction at the source. This is out of reach in a foreseeable future with available technology (and knowledge).

To what extent people are exposed to noise is, however, not only determined by the emission from the machinery, but also how the built environment is formed. Acceptable or good environments can be obtained through adequate design of city plans, building plans and constructions. It is an important task for us engineers to solve the problems caused by noise emission from machines and tools, so that people when they work, rest at home, walk in the cities, go to the cinema or theatre, etc. encounter a good acoustic environment. Closely related to this is also the design of buildings with adequate sound insulation between different activities.

Sound is an important part of human life and culture. In class rooms, meeting rooms, cinemas, theatres, concert halls, etc. the design has to be such that it is easy to speak and comfortable to listen with a high degree of intelligibility. Also these parts of acoustics belong to the professional area of the civil engineers and the architects.

In the following you will find some (but not complete) background information on the problems of noise pollution

1.2 Noise is a severe pollution of great extent

High noise levels can cause hearing impairment. This is a severe problem in industrial workplaces where much progress has been made but not sufficient. Still thousands of workers are exposed to levels which will damage their hearing. For workplace noise the commonly accepted limit has been $L_{Aeq,8h}$<85 dB for several years. It is no strict limit, but the common criterion. When the level exceeds this, action must be taken. In many cases new industries in Sweden have been designed for substantially lower noise levels. This is reasonable as the risk for hearing impairment is far from negligible at 85 dB.

Noise is also a major environmental problem. Traffic is the dominating community noise source. A larger portion of a country's population is exposed to road traffic noise than to noise from aircraft or rail. There are also other important noise sources such as noise from neighbours (e.g., lawn mowers) and building installations (e.g., air conditioning equipment) which typically are easier to control than traffic noise. Nevertheless, such sources often destroy acoustic environments that otherwise could have been quiet and relaxing, such as backyards, gardens, parks, etc. Most people are typically exposed to several noise sources. In contrast to many other environmental problems*, noise pollution is still growing* (OECD, 1996). Moreover, noise is the only environmental impact for which the public's complaints have increased since 1992 (European Report No. 2173, November 9, 1996). The development is unsustainable.

Noise affects human health and wellbeing in several ways. A Task Force of the World Health Organisation (WHO, 1993) has identified the following specific health effects: interference with communication, noise-induced hearing loss, annoyance responses, and effects on sleep, cardiovascular and psycho-physiological systems, performance, productivity and social behaviour. Various combinations of these effects are considered critical for specific environments such as dwellings, schools, hospitals, concert halls, outdoor concerts and discotheques, as well as for sensitive time periods (night- and daytime, weekends). In selecting guideline values for specific environments based on specific effects, vulnerable groups are particularly considered, for example, persons with hearing deficits, shift-workers, the elderly, infants and young children (see Berglund & Lindvall, 1995).

For community noise the common long-term goal – since the 60'ies - has been an outdoor level of $L_{Aeq,24h}$<55 dB. Several studies show that in urban areas approx. 10 –20 % of a population is annoyed or severely annoyed at that level. Therefore, this goal cannot be characterised as a good environment.

The actual European situation is summarised in a recent European Environment Agency report (Stanners & Bordeau, 1995). On average 20 % (113 million people) of the populations in European countries are exposed to 24-hour equivalent A-weighted noise levels ($L_{Aeq,24h}$) above 65 dB. Close to 50% (337 million people) live in areas with noise levels, $L_{Aeq,24h}$ between 55 and 65 dB; areas named grey zones by OECD (1986, 1991) due to serious annoyance and sleep disturbance. This means that on average 65 % (450 million people) of the population in Europe are exposed to outdoor road traffic levels exceeding 55 dB. The number of people exposed to high traffic noise levels increased between 1980 and 1990.

In Sweden, the number of persons exposed to traffic noise levels $L_{Aeq,24h}$>55 dB is approximately 2 million or 25 % of the population. Approximately 400,000 are exposed to traffic noise $L_{Aeq,24h}$>65 dB. See the Swedish "Action Plan against Noise" (Handlingsplan mot buller, SOU 1993:65).

The statistical data given above show that there is an obvious wide gap between, on the one hand, noise levels in existing situations, where abatement action is in fact also taken and, on the other, the long-term goals politically formulated. There is also a gap between these stipulated long-term goals and what represents a "good environment". This incompatibility between theory and practice results in a lack of credibility.

1.3 Acoustics of buildings

Complaints on the sound insulation in dwellings and the acoustics of classrooms and other rooms intended for aural communication have been frequent.

The strictest legislation concerns sound insulation and installation noise levels in dwellings. Minimum requirements have been in force since more than 50 years back. These requirements have been differently formulated over the years, but their ambition in physical terms has been rather the same.

Requirements on room acoustics – normally formulated as recommended reverberation time in classrooms and lecture halls - have been weaker from a legislative point of view.

Typical surveys show that 20 – 50 % of occupants in dwelling houses are more or less dissatisfied with the sound insulation when it just fulfils the minimum requirements. Nevertheless, most houses produced during the last 5 decades have not been built to any higher sound insulation standard. The main reason has been the extremely hard regulation of the dwelling house market during this time period. Since a few years back we have a new legislative situation in Sweden which has totally changed the market. A Swedish standard for acoustic classification of dwelling houses has been adopted. This has been introduced in co-operation with the building industry and has become an instrument in offering dwellings with good acoustic properties on the market. This is now an important field for product and construction development. There are several cases where we are lacking good solutions to reach the higher classes.

1.4 Sustainable development

The term sustainable development was established by the Brundtland commission and brought further in the Rio conference resulting in Agenda 21. What does a sustainable development imply in terms of noise. Reasonable requirements are the following.

- Noise which gives rise to noise induced hearing impairment is unacceptable
- Noise which deteriorates the quality of life by causing sleep disturbance, speech interference and/or severe annoyance is unacceptable.
- Noise which interferes with speech communication, learning and teaching in a society built on knowledge is unacceptable

These demands together imply that almost each tool or machine is 10 – 30 dB too noisy to fit into a sustainable development. Sound insulation between dwellings ought to be approximately 10 dB higher than today's minimum requirements to give the occupants sufficient protection.

To decrease noise emission by 10 dB means to remove 9/10 of the sound power. 20 dB means that 99/100 must be removed and 30 dB that 999/1000 of the sound power must be eliminated. The possibilities to achieve this are discussed later.

A sustainable development also involves technology with a minimum of energy and material consumption, e.g. primarily lightweight constructions of recyclable material in buildings, machines and vehicles. It is a complicating factor in achieving the goal of a sustainable development that increased weight is the most straightforward method to obtain better sound insulation in buildings and less noise from machinery.

It is a real challenge for skilled engineers to fulfil these requirements for a sustainable development in terms of noise.

1.5 The noise sources

The noise problems do not have any "end of the pipe solution". To great extent noise pollution is the effect of the emission from billions of machines and tools. Further, each individual machine may have several partial sources, e.g. a car emits noise through inlet and exhaust systems, from the engine casing and not least from the contact between tyres and road surface. Noise pollution is therefore similar to much other pollution in our environment. When it comes to community noise it is an enormous number of small diffuse immissions that need to be decreased. Sometimes noise is characterised as a local problem, because the individual source only affects a local area around it. Sometimes it is also said to be an advantage with the noise pollution that it disappears almost instantaneously when the source has been switched off. Such reasoning is misleading. Community noise as it is caused by the total sum of so many sources is a consequence of both the properties of the individual sources and the system and organisation of our society, not least its transport system. On the source side noise can only partly be dealt with through local actions.

Noise is a by-product and takes quite unnecessary energy from the useful process of the machine. However, it is only a small fraction of the power that is lost as noise. The table below shows typical values of acoustic efficiency, i.e. how big portion of the power of the machine that is emitted as noise.

Table 1. Typical values on acoustic efficiency

Normal electric motor:	$2\ 10^{-7}$
Jumbo jet aircraft:	$1\ 10^{-6}$
Low pressure fan	$1\ 10^{-6}$
Human voice	$5\ 10^{-4}$
Common direct radiating loudspeaker	$5\ 10^{-2}$

These values show that machines are rather ineffective as sound generators. As a matter of fact it is difficult to obtain a real high efficiency. The human voice - evolved during very long time - is a rather inefficient acoustic generator. An ordinary loudspeaker is more effective but nevertheless it only has an efficiency of approximately 5 %. Most machines have an acoustic efficiency less than 10^{-6}. The problem is that also such a small resulting sound power can cause a lot of annoyance and damage because the human hearing organ is so sensitive.

To solve noise problems through changes of the source implies to decrease the acoustic efficiency – which is already very small – with some more orders of magnitude. It is a long-term, often very tedious work to reach any results in terms of decreased noise emission at the source. It needs both research and development. Innovative engineers with a good knowledge in acoustics and machine design here have a vast work field.

For products that have not been acoustically optimised it is often possible to reduce the noise emission by 5 dB or so. 10 dB may be possible but more than so normally demands extensive changes of the construction. When it comes to well designed industrial products these 5 – 10 dB have already been taken. Noise reductions of the order of 20 – 30 dB demands radical change of technology as for instance the change from mechanical typewriters to word processors or change from car to bicycle.

One of the few examples of a very successful noise reduction at the source is the jet engine on commercial aircraft. The first jet air craft for passengers were introduced in the mid 50-ies. They were extremely noisy and resulted in a dramatically increase of the noise around airports. Fortunately the first generation of jet engines was soon followed by a second generation, the so-called by-pass engines. They used a new engine construction where the jets had a much reduced velocity but in compensation an increased mass flow. Commercial aircraft got much quieter. However, the by-pass engines were not developed because of the noise problem, but because they have better economy and higher force at low speeds enabling big jet aircraft to take off from run ways of reasonable length.

In our technological culture it is common to increase the speed. Increased speed also leads to increased noise. Depending upon the noise generation mechanism the acoustic power increases by 6 – 24 dB for a doubling of the speed. The highest value – 24 dB – is that of a jet. Military aircraft cannot use the mentioned by-pass engines and therefore their engines get noisier with increasing speed demand. JAS is one example of this.

Most machines have several noise sources, which may have different character. Some examples on noise increase with velocity are shown in table 2.

Table 2. Examples on noise emission for a doubling of the speed.

Tyre noise	10 – 12 dB
Other car noise	10 – 12 dB
The Swedish rapid train X2000	6 – 8 dB
Maglev train at high speed	18 dB

1.6 Means of achieving a good acoustic environment

It is clear that the noise problems cannot be solved entirely by noise reduction at the source. The individual buildings and the entire community has to be so designed that the environment to which people are exposed are acoustically good or at least acceptable. This means that noise sources have to be sufficiently well separated from people. This is done by having sufficient attenuation in the transmission path from source to receiver. The means are distance, barriers and sound insulating constructions. These must be integrated in the built environment considering other functions and with a minimum of resource use. This is an interesting work field for engineers well trained in acoustics.

1.7 Costs of noise and inadequate acoustics

Noise costs in terms of reduced quality of life, sleep disturbance, speech interference, hearing impairment and annoyance. Lack of acoustic comfort reduces the sales of products. Inadequate acoustics in classrooms, theatres, etc. costs in reduced efficiency in teaching and learning and reduced satisfaction and reduced usefulness.

How much does it then cost to reduce noise and/or achieve adequate acoustic quality? That depends upon when the noise problem is tackled. There is no law of nature that says that a quieter machine is more expensive than the noisier one. Figure 2 shows in general terms the relation between acoustic quality and cost.

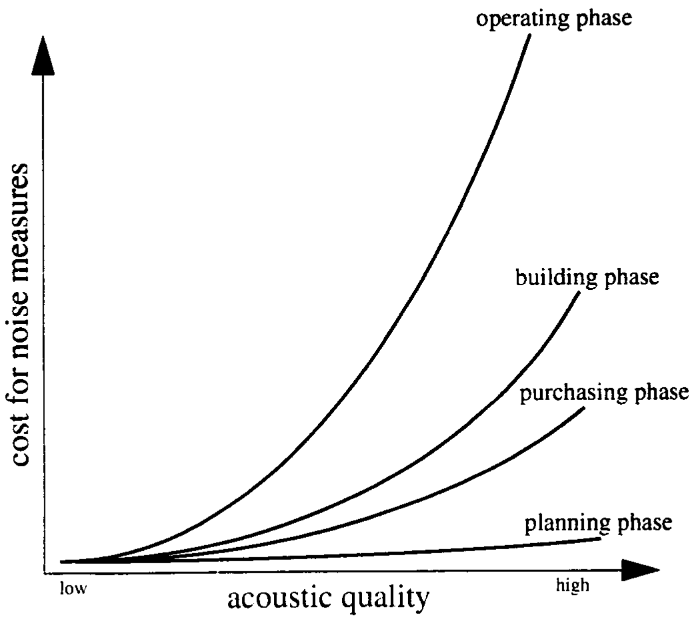

Figure 2. Relationship between cost and acoustic quality.

It is obviously important to take adequate action in time. If the acoustic quality demands are tackled with adequate competence at adequate time the cost increase for the higher quality is low. To solve a noise problem which is already established, improve the sound insulation of a building that is finished or to improve the acoustics of a concert hall afterwards is on the other hand in common cases 10 – 100 times as expensive. The increased cost for a dwelling house with very good sound insulation is 0.5 – 3 % higher than for the normal building, if it is taken into account in the construction at the design stage. On the other hand to improve a dwelling house which just meets the minimum requirements in terms of sound insulation so that the sound insulation gets considerably higher has in most cases only one technical economic solution. To demolish the house and start from the beginning with higher competence.

The quiet ventilation system in a house demands fans and ventilation channels, which are correctly designed from the flow point of view and is therefore somewhat more expensive to buy and install than a common noisy ventilation system. However, the energy consumption is so much lower that the total cost over the life time of the system gets lower. On the other hand to insert such ventilation system in an existing house is often not very easy because the ventilation system is an integrated part of the building.

It is in the early stage of new projects or renewal projects or before the contract on a new machine is signed that we have the opportunity to get high acoustic quality at a reasonable cost. The increased cost, if any at all, for the high quality is typically sufficiently well above the average willingness to pay for the higher quality. In a long-term work ambitious goals for the acoustic quality can be reached at a reasonable cost, but it demands continuous attention and action. On the other hand, lack of action with sufficient competence at the right time often gives as result products and built environments that are acoustically bad but where the owner cannot afford to correct the situation.

As the acoustic properties are so integrated in products, buildings and the entire built environment, acoustics needs to be an integrated part of the engineers' competence.

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