

Activities in Acoustics of European Research Centers and Companies during the 20th Century

Contributions to a Structured Session at
Forum Acusticum 2023 in Torino

Editor

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This booklet is based on the contributions submitted to the corresponding structured session

Activities in Acoustics of European Research Centers and Companies during the 20th Century

as run from September 11 to 13, 2023, at Forum Acusticum 2023,
the 10th Convention of the European Acoustics Association, EAA,
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This session had been jointly organized and was chaired by

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Foreword

This booklet originates from a structured session being held at Forum Acusticum 2023, the 10th Convention of the European Acoustics Association, EAA, which was run in September 2023 in Torino, Italy. The initial idea for this session was to compile, update and provide some existing but widespread information on important contributions from prominent European institutions to the development of acoustics in the second half of 20th century. Such information was limited so far to occasional reviews of institutional activities in major industrial nations, and it was seen to be promising not only to bring these together but also to complete them by reviewing respective activities in other European countries.

This promise could be fulfilled with great success in the end. 37 papers from 21 European countries were able to sketch a multi-faceted picture of acoustic development in the equally diverse spectrum of European countries and scientific environments. For two full days, the many presentations and discussions were an excellent opportunity for the interested community to exchange historic experiences, review the milestones of physical/technical development and assess progress and achievements of that time with respect to the relevance of acoustics today.

In addition, the submission of 37 papers can be seen as a value by itself which was to be given a superior, long-term visibility and availability. This is the basic sense and purpose of this booklet: to combine the collection of these papers and to make them easily accessible to all being interested in such historic matters.

Editors and authors are most grateful to the European Acoustics Association, EAA, and the congress organizers of Forum Acusticum for their support in both, implementation and provision of this booklet on their websites, above all in the online portal of EAA, Documenta Acustica Electronica (DAEL, see <https://dael.euracoustics.org/>). We hope, this will set a starting point for a continuously growing archive of historical information on our important technical subject, the wide interdisciplinary field of acoustics in Europe.

The 37 papers of this booklet are structured along some classification which tries to compromise between temporal and geographic assignments. Both these assignments are too much interrelated to allow strict and unique sequential orders. However, just because the many cross references withstand - by their nature - sequential arrangements and reading, they may provoke a back and forth jumping study of the subject which is the only adequate way to explore and recognize historic developments and dependencies.

To appropriately introduce and embed the 37 papers, the following editorial will help to see them in their historic context. Based on a condensed summary and classification of the history of acoustics, the scope of the session - which is the scope of this booklet too - will set a frame for the many and most different activities of acoustic institutions in 20th-century Europe. Further, a short report on how the session was run and what were its essential conclusions and recommendations in the end, will try to summarize the resulting outcome beyond the text of its papers.

The editor expresses his explicit thanks to all who made this booklet possible: all authors and contributors to the session and - above all - the European Acoustics Association, EAA, and its 10th convention, Forum Acusticum 2023, for their continuing support in preparing and running the session and in publishing and providing the booklet.

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Editorial

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Introductory Notes to the History of Acoustics

The history of acoustics dates back to the very beginning of human exploration of the world and its phenomena. This is quite natural because acoustical phenomena, acoustic perception and acoustic communication as well as generation and enjoyment of pleasant sounds definitely belong to the basic prerequisites of higher life. Consequently, even if it was not called acoustics yet, acoustics was a matter of consequent research efforts since very ancient times ([1]-[4]).

This section will shortly review the history of acoustics in broad lines, to set the basis for the subsequent collection of papers which then will deal with the details of European research centers and institutions and their acoustic activities in 20th century. The description closely follows the compact review given in [5].

Of course, due to being strictly limited by its introductory nature, this review is doomed to fail any completeness. Therefore, instead of referring to the many partial disciplines resulting from acoustics being multiply interdisciplinary by its very nature, this review tries to emphasize the main driving force in 20th century. For this period, this driving force may be found in the needs of progressive mechanization, industrialization and communication which required substantial progress in recording, storing/transferring, reproducing and, in a wide sense, controlling sounds, i.e. in technical and engineering acoustics. However, this highlighting cannot degrade the great significance of the many other branches of acoustics such as flow acoustics, ultrasound, musical acoustics or psychoacoustics.

Acoustics before 1900

Over the centuries, the results of research efforts and investigations combined to partial completeness which, in the nineteenth century, then caused systematic research for full understanding of the underlying physics ([6]). This was achieved in the second half of the century by the outstanding work of Hermann von Helmholtz (“On the sensations of tone”, 1862, [7], fig.1 left) and Lord Rayleigh (“Theory of Sound”, 2 volumes, 1877 and 1878, [8], fig.1 right), who were able to explore and explain a great variety of acoustic phenomena and mechanisms and to subject them to a closed theory, the theory of sound.

Helmholtz himself stated that Rayleigh had given “a complete and coherent theory of sound with application of all the resources furnished by mathematics” without which “a really complete insight into the phenomena of acoustics is altogether impossible” [6]. Thus, mathematical physics had found their way into acoustics, and this was conclusively crowned by the key work in Mathematical Physics of David Hilbert and Richard Courant (2 volumes, 1924 and 1937, [9]).

With the complete theory of sound, physics of 19th century had succeeded to provide a widely comprehensive and conclusive understanding of physical acoustics. However, as later again, this had the effect that acoustics was seen - and underestimated! - as a practically completed discipline without new scientific challenges. But the challenges were to come with new progress in physics and technology and with new demands to acoustic quality of life.

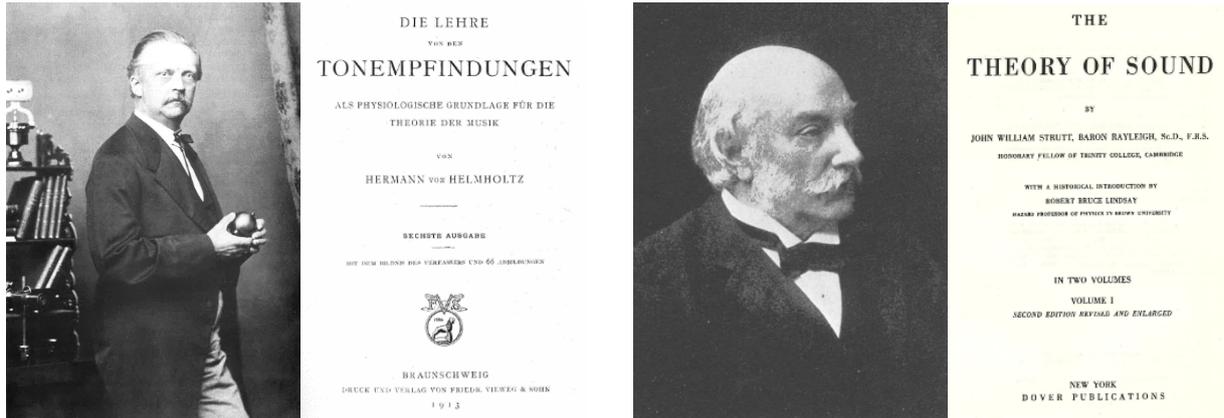


Figure 1. Hermann von Helmholtz with Helmholtz resonator and front page of his book “On the Sensations of Tones” (left) and Lord Rayleigh and front page of his book “The Theory of Sound” (right)

Acoustics in first half of 20th century - from physical to technical acoustics

The invention of the telephone by Philipp Reis (1861), the foundation of electrodynamics by James Clerk Maxwell (1864) and the evidence of electromagnetic waves by Heinrich Hertz (1886) caused a rapid development of electrical communications and broadcasting ([6]). As the transmission quality of acoustic signals crucially depended on the quality of acoustic (recording and reproduction rooms) and electroacoustic (microphones, loudspeakers, storage etc.) components, this also caused a rapid development of electro-acoustics including new measurement approaches and technologies.

Thus established, technical acoustics was the starting point for growing relevance and involvement of acoustic issues within the process of industrialization in 20th century. At first, this development focused on providing and supporting desired sounds (electric sound recording, transmission, reproduction and distribution). In addition to developing and extending worldwide broadcasting of sound signals via telephone and radio networks as well as tape and disc recordings, it was W.C. Sabine who was able to lay a solid foundation for targeted acoustic design and layout of auditory rooms to best adapt them to the perception of speech and music.

However, reduction of undesired sounds by technical means was increasingly recognized as an important discipline too, indispensable even for progressive mechanization of our world. Significantly interested circles thus were sure in the early 20th century already that noise abatement was a public duty, being claimed for instance by early lobby groups like the first German noise abatement society founded in 1908.

Physical and technical acoustics tried to meet the respective requirements by successful research activities as well as by new findings and development results. Apart from complementing and completing the far-sighted frameworks of Helmholtz and Rayleigh, this led to increasingly systematic investigations of sound generating, sound transmitting and sound controlling mechanisms. Some exemplary findings were

- Berger’s mass law (1910) for sound insulation of walls
- Derivation and validation of practical approximation formulas
- Introduction of “dB” (1920s) and “phon” (for loudness by Barkhausen, 1926)
- Fundamental investigations on structure- and fluid-borne sound
- Investigations and design of porous wedge absorbers for anechoic rooms

- Derivation and experimental verification of coincidence effect by Cremer and Eisenberg (1942/48)
- Development and provision of versatile measurement technology and instrumentation using new tube technology
- Development and provision (by literature) of theoretically and empirically well-founded state-of-the-art reports for the most important subdisciplines of technical acoustics.

In total, in the middle of last century, technical acoustics may be described as a discipline which felt committed to the fascination of new technical possibilities (electro acoustics) and quality-conscious hearing requirements (room acoustics) but also to the still weak social awareness of detrimental noise effects (noise control). By orientating successive insight along the requirements of increasing mechanization, acoustics had been able to recommend itself as an important instrument of prudential engineering activities: Being - at that time - formally mostly associated with communications technology (electro-acoustics) or mechanical vibrations and waves (room-/building acoustics and noise control), technical acoustics had been developed to a high level and was ready to become engineering acoustics.

But again, as in early 20th century, from a scientific point of view, acoustics was seen to be a widely completed discipline, lacking new scientific challenges. For young students making their choice for the field of their studies in the mid of 20th century, acoustics just appeared to be old-fashioned and unattractive. But again, great challenges were there, ready to involve and further develop existing acoustic methods and skills.

Acoustics in second half of 20th century – from technical to engineering acoustics

The disastrous consequences and destructions of World War II had abruptly ended the successful work of many prestigious research institutions in Europe. While these were subject of new orientation and rebuilding, rapid housing reconstruction needed immediate and competent acoustic support. Fast and cheap reconstruction methods ruthlessly uncovered deficits in knowledge and quality defects. Also, growing prosperity later implied increased demands for comfort and quality of life. Thus, noise reduction and acoustic comfort soon forced acoustics to be consequently involved in an interdisciplinary way with relevant engineering disciplines. Well-developed technical acoustics was not only ready, it was strongly forced to become engineering acoustics. This is convincingly described in various memoirs and memories (see [10] and [11] as examples).

At the time, this development may have been most obvious for the wide area of noise control. Although its spectrum was flexibly varying from the very beginning, the main focus of noise control activity in the fifties was on building acoustics. But soon, when practicable design rules for acceptable acoustic building standards were available, the focus was extended to industrial noise control in the sixties and to traffic noise control from the seventies on. This shall be shortly reviewed in the following.

For building acoustics, starting point in many countries were ambitious building programs aimed to use cheap and light building materials, soon with preference for prefabricated elements. However, without proper design rules this was likely to end up with poor acoustic quality. Consequently, research for better design rules soon was focused by up-to-date research institutions. Thus, reduction of noise and sound transmission in buildings was not only an issue for existing or rebuilt institutions but also for new research institutions to be founded.

Typical examples are the Institute of Technical Acoustics (ITA) at Technical University (TU) of Berlin (founded in 1954, see paper 9, page A59) and the extension of an early acoustic lab (founded by Per Bruel in 1943/44) to an Institute for Applied Acoustics at Chalmers Technical

University in Gothenburg (Sweden) in the end of the sixties (see paper 4, page A23). They both were strongly committed to scientifically support ongoing building activities. The extension of the Institute at Chalmers was motivated even by a huge “million programme” to build one million flats in very short time with newest building technologies.

Building acoustic activities often were linked with room acoustic design applications where sound isolation and noise control requirements had to be combined with optimal sound distribution requirements in auditoria. Successful design solutions for all these tasks depended on the availability of high-performance measurement rooms and equipment. Innovative pioneering examples were the

- Berlin Philharmonic Hall, where new acoustic concepts and elements were able to cope with new room concepts and to give them reference status in the end (see paper 9, page A59) and the
- new anechoic room in Göttingen (Germany) which, in 1954, even served as cover photo for a special issue of the US-magazine “Life International” on “Germany, the awakening giant” (see paper 8, page A51).

Next to architectural acoustics, industrial noise control soon appeared to be another crucial field of application and thus another dominant driving force for further developing the toolbox of practical engineering acoustics. Although the physics involved with these tasks basically were understood, it needed a lot of tests and measurements to find practicable models and to identify influential design parameters.

This had been exemplarily verified for petrochemical plants, typically spread over large areas in open air due to risks of explosion. Instead of building enclosures around the plant or parts of it, separate control of the many complicated sources and mechanisms required stringent but balanced control measures at all relevant sound sources (e.g. primary measures at valves and fans) but also at appropriate sound transmission paths (e.g. secondary measures like encapsulation, blow-out or inline silencers). In the end, essential reductions of the sound power of industrial plants provided evidence that even large industrial installations could be operated in an environmentally compatible way in densely populated areas.

It thus was natural that rapid traffic growth soon became the major noise problem. Among the many contributions to vehicle acoustics and traffic noise control, early pioneering work was applied to provide predictive estimates of traffic noise for roads and rails. However, no tools for predictions such as in today’s noise maps were available, they still had to be developed. It took decades to complete, implement and provide, step by step, the large toolbox of clear standards, guidelines, design rules and extensive software packages we are used to have today. But the foundations were laid in the early seventies.

Instead of passively reducing the incidence of noise it usually is much more efficient to actively reduce the generation, the radiation of noise. Of course, this was known from the very beginning of noise control already but to do so it was important to understand the generating mechanisms of sound. However, as rolling noise is the dominant noise source for road and railway noise, the respective generation was a matter not sufficiently understood in the first after-war decades of last century. It took until the seventies that rolling noise was investigated systematically and it took some more decades until the mechanisms involved were sufficiently understood to provide reliable models and design rules for low noise wheel/rail constructions, low noise tires and low noise road surfaces.

The above-mentioned application areas and examples may illustrate that engineering applications have been the major driving force for the renaissance of acoustics in the second half of 20th

century. It is self-evident, however, that the successful development and application of problem-specific acoustic methods and guidelines equally necessitated advancements in physical and methodological basics of acoustics. Impressive examples of pioneering progress were, for instance, a deepened understanding and modelling of flow induced aerodynamic sounds and a breakthrough in computational acoustics because of rapid electronic progress. Also, the new era of digital measuring procedures opened unforeseen possibilities of registering and then understanding acoustic phenomena.

In addition to all physical/technical progress, systematic research of human sound perception and assessment opened new possibilities for aurally adequate evaluations and assessments of sounds. The successful establishment of psychoacoustics as complementary approach to a holistic concept of acoustics substantially contributed to better align acoustic measures in all areas with human needs.

As stated above and described in detail in [10] and [11], the growing need to apply acoustic expertise and know-how to practice after world-war II required acoustic consultancy. Being mostly provided by sideline-activities of academic institutions and persons first, it soon became a fulfilling activity of acoustic consultants and consulting offices and of acoustic engineers and departments in (larger) companies later. Acoustics and engineering acoustics were to become an independent profession, thus establishing engineering acoustics as an autonomous (inter)discipline amidst all engineering disciplines.

Summary

Driven by progress and requirements of the advancing machine age, Acoustics of the 20th century has run through a tremendous development. Starting from a profound understanding and formulation of its theoretical physical framework by Lord Rayleigh and Hermann von Helmholtz at the end of the 19th century, acoustics and its many subdisciplines developed to an indispensable technical and engineering discipline which, at the beginning of the 21st century, has become a basic design tool for environmental compatibility and comfort features of most technical products.

Of course, this development is based on many particular achievements resulting from both, scientific physical as well as practical technological progress well spread over the century. However, in retrospect it seems that fast reconstruction requirements in Europe after World War II have enforced particular interactive efforts of research institutes and companies to cope with the challenges of that time, thus significantly emphasizing the relevance of modern acoustics.

Based on the contributions to Forum Acusticum 2023, this booklet tries to trace such efforts in various European countries.

Session Report

Structured Session - Scope and Objectives

In the past, only some of the before mentioned historic efforts of institutions and companies had been investigated and reported. These reports had been prepared and presented occasionally rather, typically for anniversaries and their celebration. As a consequence, respective conference sessions were poorly supported and thus were confined to limited sections of mostly national reviews only.

The basic idea for the structured session at Forum Acusticum was to focus on diversity and comparison of similar efforts in different institutions and to do this in a European context. Therefore, the session aimed to identify relevant European contributors from both areas, research institutions and companies, and to review their respective achievements which, in the end, were able to renew and establish acoustics as an indispensable interdisciplinary field of sustainable progress and technology. In particular, trying to provide a complete overview, the session had invited contributions to the history of any subdiscipline of acoustics like, among others, noise control, sound design, room and building acoustics, ultrasound, electroacoustics, psychological and physiological acoustics, sound measurements and sound assessments as well as the development of respective standards and guidelines.

Structured Session - Report and Outcome

With 37 contributions from 21 European countries, the session has exceeded highest expectations even. Although some major institutions had not been able to follow the invitation, the 37 papers gave an excellent overview on what happened in European acoustics in 20th century, particularly in its second half. It thus was able to impressively demonstrate how European acoustics became what it is today: a rich and diverse, vivid and fertile landscape of acoustic knowledge and applications. The mere existence of 37 historic papers from 21 EAA member societies definitely is a value by itself and will provide an excellent and retrievable entry point to explore the history of our discipline. It thus was felt that the historic session in Torino was historic by itself.

37 presentations, each of which having a time slot of 20 minutes, needed more than 12 hours of session duration, thus filling two complete conference days. Although competition with the many parallel sessions of Forum Acusticum was high, the session attracted an average audience of 50 to 100 participants who took the chance to complete the material presented by asking questions and making comments. Many of them were surprised by their own fascination which urged them to stay with the session much longer than they had planned.

This fascination had good reasons - a rich variety in many aspects:

- great national diversity reflecting specific historic, cultural, societal, scientific and political conditions and experiences,
- institutional diversity reflecting multiple differences in scientific tradition and expertise,
- differences in age of both, presenters and participants of discussion, thus ensuring the concurrence of personal experience and historic memories with present curiosity.

However, with all this diversity, some typical patterns of historical development showed themselves to be obvious and applicable. Based on the specific scientific level of national research institutions, it was the abrupt occurrence and awareness of noise problems which triggered a stimulus first and maintained a momentum later to (re)start own acoustic activities and keep them running later then.

In most of the reports given in the session, it was pointed out that the beginning of conscious acoustic activities was closely linked to research and development in building acoustics, followed later by extensions to other areas of sound and noise control. However, the timeline of these national activities turned out to be very different and strongly dependant on the stage of economic and industrial development.

So, all in all, apart from fixing many details of acoustic progress in 20th century, the structured session in Torino successfully fulfilled its claim to trace the multifaceted development of acoustics in Europe. Although, for most countries, the renaissance of acoustics in the past century followed a repetitive pattern in delayed time frames, individual differences due to different scientific traditions and political/societal circumstances could be identified.

The fascinating details of these acoustic stories are found in the conference papers of the session at Forum Acusticum as compiled in this booklet. They fully correspond to the papers in the proceedings but are put together here again for compact and easy reference.

Summary and Conclusions

The innovative initiative to review what may be called the renaissance of Acoustics in the second half of 20th century by focusing on research centres and companies spread all over Europe was crowned by unexpected success. 37 historic contributions from 21 European countries being presented at a structured session of Forum Acusticum 2023 impressively demonstrated the increasing demand for technical acoustic expertise in 20th century and the resulting increase in both, state of the art and relevance of Technical and Engineering Acoustics.

Despite all differences in the specific national developments, a uniform development pattern could be identified in the long term. It thus was shown that the consequences of technical globalization and the resulting spirit of the time (zeitgeist) finally achieved to overcome cultural and societal differences. However, the details and the differences of national developments altogether were able to expand the range of practical and theoretical foundations in applied Acoustics.

Taken together, all these developments have contributed to the unprecedented boom that has made acoustics a highly significant and indispensable interdisciplinary field of modern technology. Moreover, the growing relevance of technical and engineering acoustics has essentially claimed and promoted new and further progress in general acoustics which subsequently resulted not only in expanding the fundamentals of acoustics but also in opening up many special areas of application. This is why the technical and scientific development in the early second half of the last century often is rightly referred to as a renaissance of acoustics. This so-called revival of acoustics was able to turn and maintain the classical branch of physics to an important discipline of modern science and technology. The compilation of papers in this booklet excitingly traces and illustrates this complex development against the diverse background of European countries.

Outlook and Future Activities

During the discussions at the meeting, it was already expressed that the obtained collection of materials should be maintained and expanded. The most favourable proposal how to preserve, provide and maintain the collected papers in the long term was to give them – in addition to the conference proceedings – a separate and independent stand-alone visibility. This is what we try to realize with this electronic booklet, hoping that it will reach out to a wider public.

Once being provided, this booklet could become the starting point for a permanently available and continuously expanded database on the history of European acoustics. Taking up a proposal

from the floor of the discussion at the session itself, the content of this booklet could be archived and permanently kept available within a newly set up document repository of the EAA database, Documenta Acustica Electronica (DAEL).

Such a “historic” internet platform would allow and consequently claim for continuous maintenance in both, extension and updating actualisation on a multinational and multilingual level even, by involving language translation utilities provided by the European Union. Thus, if set up purposefully, these conference papers might serve as nucleus for a broad, open access data base of the history of European Acoustics and Acoustic Societies.

A successful example how this approach can be implemented in practice is the special issue of the magazine *Acoustiques & Techniques* as published by the Centre d’information sur le bruit (CidB) and the French Acoustical Society (SFA) for the Inter-Noise Conference 2024 ([12]). In this special edition, a set of 14 articles has been put together to describe the past, present and future expertise of acoustic research laboratories in France. It would be most promising if the success of the session at Forum Acusticum 2023 in Torino could be continued in this way and expanded into a continuously updated and permanently available source of information on the history of European acoustics.

Acknowledgements

The impressive collection of contributions to the history of Acoustics in European research centres and companies was only possible thanks to the active support of many. Of course, this first and foremost applies to the authors and co-authors of the 37 papers compiled here. But such a compilation requires the sparkling idea first and its persistent realisation then.

In this sense, this booklet owes its existence to the topic organisers of Forum Acusticum 2023, Luigi Maffei and Karolina Jaruszewska, who had the idea to consequently extend the concept of earlier historic conference sessions to a comprehensive survey of related initiatives and activities throughout Europe. And since nothing can better justify an idea than its success, recognition and thanks are due to all those who have made this success possible.

After some clarifying discussions, Joachim Scheuren (editor of this booklet) and Andrzej Dobrucki accepted the invitation to jointly organize a respective structured session at Forum Acusticum 2023 in Torino, Italy. Then, to come up with a broad and representative selection of contributions from among the many member societies of the European Acoustics Association EAA, the session organizers started a systematic exploration of the European acoustic landscape of the last century and finally succeeded to commit the 37 articles published here.

However, all these contributions had to be invited and coordinated with each other and then to be subjected to the mandatory review process as prescribed by the Forum organizers. Therefore, extraordinary thanks are due to all those who have contributed to this process: the congress organizers including the Congress and Technical Program Chairs, the many reviewers providing 74 (2 per paper) reviews, the authors and - above all – the co-organizer of the session, Andrzej Dobrucki, who successfully shouldered the main burden of organisational session preparation.

Finally, special thanks are due to the European Acoustics Association EAA and its representatives for supporting and realizing this booklet. In particular, the secretary of EAA, Joana Leitão Teixeira, together with Ela Faslija has significantly supported the appealing design and graphic realisation as well as the long-term provision of the booklet.

On behalf of all who have contributed and of all those who will use the booklet or benefit from it, the editor expresses his sincerest thanks to all those who have made it possible.

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Collected Papers of the Session

All papers listed here and compiled in the appendix are also posted on the website of Forum Acusticum and can be found at <https://dael.euracoustics.org/confs/fa2023/data/index.html>. For easy reference, the respective Forum paper numbers are listed in the right column.

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APPENDIX

**Collected papers as provided to the structured session
“Activities in Acoustics of European Research Centers and Companies
during the 20th Century”
at Forum Acusticum 2023**

This appendix provides - in the sequence and with the page numbers of the previous list of collected papers - a reprint of all papers as they were provided for the structured session at Forum Acusticum 2023 and as they are found on the respective website

<https://dael.euracoustics.org/confs/fa2023/data/index.html>.



THE PRE-HISTORY OF 20TH CENTURY ACOUSTICS: THE LEGACY OF LORD RAYLEIGH

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ABSTRACT

Rayleigh's two-volume work "The Theory of Sound" was the crowning glory of 19th century acoustics, and it set the agenda for everything that followed in the 20th century. The talk will review Rayleigh's life and key contributions, which covered structural vibration as well as airborne acoustics. His interest in wave theory also extended to optics: he famously explained why the sky is blue. The talk will include images from the surviving laboratory at Terling Place, the ancestral home of the Rayleigh family. Apparatus associated with some of Rayleigh's iconic experiments in acoustics can still be seen there. A flight of stone steps in the grounds was an early inspiration for the theory of diffraction gratings, and this was followed up by an ultrasonic experiment involving a periodic array of muslin discs with variable spacing.

Keywords: *Acoustics, Lord Rayleigh, Wave theory*

1. INTRODUCTION

Lord Rayleigh (1842–1919) was a giant of 19th-century science. He was the "godfather" of British acoustics, and he also worked on all the other major areas of physical science of his day. He wrote some 450 scientific papers. He was the first to explain why light from the sky is blue (and also polarised) [1, 2], and how it is that seabirds can soar for long distances without flapping their wings [3]. He shared the Nobel prize in 1904 for the discovery of argon.

But this paper centres around his two-volume work "The Theory of Sound", first published in 1877-78 [4].

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Volume 1 deals with structural vibration, Volume 2 with airborne sound. Both volumes give a complete summary of knowledge in his day, much of the material consisting of original contributions by himself. A second edition came out in 1894, and a telling detail is that for this revised edition he added sections on the "new-fangled" electrical circuits which had come to prominence between the two dates. The general theory he had developed for discrete vibrating systems could be applied directly to capacitor/resistor/inductance circuits — an interesting inversion of the tendency in the 1950s and later to analyse vibration problems using electrical circuit analogies.

2. HISTORICAL MATERIAL

When the Cavendish Laboratory was first established in Cambridge, James Clerk Maxwell was the first holder of the Cavendish chair. But Maxwell died tragically young, and the University of Cambridge prevailed on Rayleigh to do a 5-year stint as Cavendish professor of physics, to get the new lab on its feet. He succeeded spectacularly in this task, setting the Cavendish lab on the road to becoming the global force it is today. After that, Rayleigh needed to return to his family estate at Terling Place in Essex, so in order to continue his research activities he converted various spaces in the house into laboratories. These are still present, together with quite a lot of Rayleigh's experimental apparatus — for example the sensitive balance used for the work on the density of air which led to the discovery of argon.

One example concerns work on diffraction gratings. In the grounds of Terling Place is a flight of stone steps, in a setting with no other strong acoustical reflections (see Fig. 1). If you clap your hands in front of these steps, you hear a tonal echo. According to family legend, this may have inspired the young Rayleigh to investigate the reflection of sound and light by periodic structures.

He developed the theory, and one experiment used to





Figure 1. Steps at Terling Place.

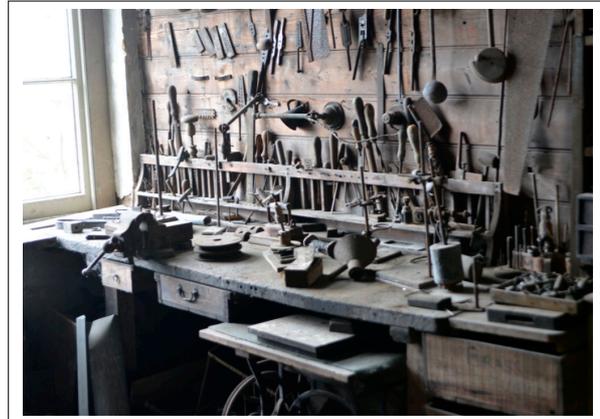


Figure 3. Rayleigh’s laboratory workshop.

test the predictions is shown in Fig. 2. A set of muslin discs is fixed to a “lazy-tongs” arrangement so that the regular spacing can be varied. The rig was no doubt built in the workshop shown in Fig. 3. In those days before electronic test equipment, he used as his ultrasonic sound source a “bird call” whistle, and to detect the intensity of the resulting sound field he used a “sensitive flame”. With this primitive equipment he was able to verify the predictions of his theory. Two “bird calls” can be seen in Fig. 4, resting on the lid of their storage box still bearing Rayleigh’s handwritten list of the frequencies and wavelengths.

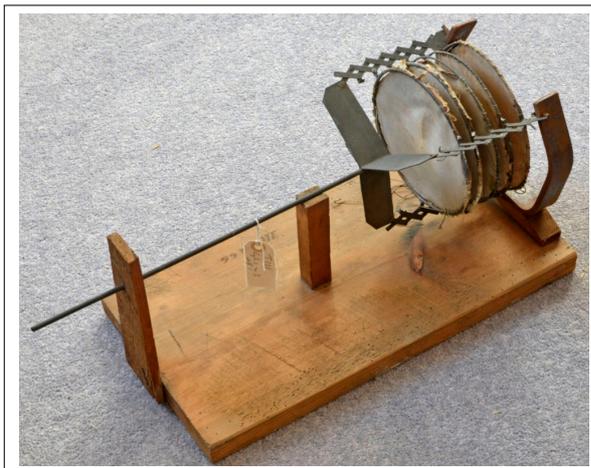


Figure 2. Rayleigh’s diffraction experiment.

3. RAYLEIGH’S SCIENTIFIC LEGACY

An important theme in Rayleigh’s legacy, still relevant to teaching undergraduates today, is his talent for making telling use of general principles to cut through the detail of a complicated problem, and reveal the main structure in the simplest way.

An example is his pioneering use of dimensional analysis. Consider a bending “Euler beam”. The only dimensioned parameters that enter the problem are the mass per unit length m , the bending rigidity EI (Young’s modulus times the second moment of area of the beam cross-section), and the length L . Rayleigh pointed out that there is only one way to combine these to make a quantity with the dimensions of frequency, so *any* natural frequency ω_n of *any* such bending beam must be determined by an equation of the form

$$\omega_n = \frac{K}{L^2} \sqrt{\frac{EI}{m}} \quad (1)$$

where K is a non-dimensional constant.

Another famous example is “Rayleigh’s principle”, bounding the eigenvalues of a discrete vibrating system in terms of potential and kinetic energy expressions. Rayleigh introduces this important principle in the early chapters of Volume 1, and subsequently uses it to draw both quantitative and qualitative conclusions for many problems. But this is the tip of an iceberg. Rayleigh made extensive use of maximum/minimum variational principles for many purposes: to derive governing equations, to resolve a controversy about the correct boundary conditions at a free edge of a thin bending plate, to carry out a wide range of perturbation analyses.



Figure 4. ‘Bird calls’ and Rayleigh’s handwriting.

There are many other examples of the “Rayleigh mindset” dotted through *The Theory of Sound*. The chapters on “Vibrating systems in general” contain many general theorems such as the eigenvalue interlacing theorem (now commonly known as the Sturm sequence property). In the form relevant to vibration, this states that if you change a discrete linear system by adding or removing any single constraint, the natural frequencies before and after the change must interlace one-for-one. Rayleigh made clever use of this result to make simple deductions about the behaviour of complicated systems.

A final example from Volume 1: in the second edition, material was added about the vibration of “curved plates or shells”. Rayleigh made the important observation that if a shell is geometrically capable of *inextensional* deformation (no stretching or shear in the middle surface) then by the energy-minimisation principle, those deformations are likely to give a good approximation to low-frequency vibration modes. He applied this idea to hemispherical shells and the vibration of church bells.

In the field of wave theory, Rayleigh’s work on diffraction gratings has already been mentioned. Volume 2 of *The Theory of Sound* also contains many examples of a style of analysis that was later to be formalised as the method of “matched asymptotic expansions”, and play a very significant role in 20th century acoustical theory.

He was equally interested in wave problems in optics. He was the first to suggest that the iridescent colours of certain crystals, and also of some insects, such as but-

terfly wings, were the result of “structural colour” rather than pigment [5]. He suggested that the microstructure of the crystal or the butterfly wing either had layers (like the muslin disc rig) or approximately periodic surface features (like the flight of steps). His hypothesis was correct, and it was the subject of further research by his son, the 4th Lord Rayleigh [6]. Figure 5 shows some iridescent insects collected by the Rayleighs, and still in their study at Terling Place. Structural colour is the reason these are still as bright now as on the day they were collected: pigment would have faded.



Figure 5. Iridescent insects, collected by Rayleigh and his son and still to be found in a desk drawer in their study at Terling.

As well as being a master of acoustical theory, Rayleigh was also closely involved with practical applications. An example, connected with his work on wave theory and diffraction, concerns foghorns (used before the days of GPS to warn ships of dangerous waters during foggy weather). Rayleigh was consulted about a serious problem: ship’s captains had reported that from certain directions they were unable to hear the foghorn, even when they were quite nearby. He correctly diagnosed the problem as resulting from null directions in the sound radiation pattern of large horns. The solution was to build the horns like the example shown in Fig. 6, with an elliptical section. The horizontal dimension needs to be small compared to the wavelength of sound, to ensure omnidirectional radiation with no nulls, but it is an advantage if the vertical dimension is larger, to concentrate the sound in the horizontal plane where it is needed. The authorities did not believe this counter-intuitive design until he built a demonstration model and showed them!



Figure 6. An elliptical foghorn near Whitby, from a design by Rayleigh.

Of course, there are things that Rayleigh did not know about, back in 1877. To modern eyes, the most obvious missing ingredient in *The Theory of Sound* is the frequency domain viewpoint. The idea of frequency response functions, let alone the ability to measure them, had to await the development of electronic test gear in the 20th century. Similarly, although Rayleigh's treatment of the general linear theory of discrete systems is very sophisticated, it does not use the language of matrices: those only became familiar in the world of physics with Heisenberg's version of quantum mechanics, long after Rayleigh's time. At a more trivial level, the reader is struck by the fact that the partial derivative symbol had not yet been introduced. But these things do not detract from the power and magic of the two books: *The Theory of Sound* is one of a very select group of books of that age which are still valued as working textbooks, and not just as historical curiosities. That, perhaps, is the real mark of Rayleigh's greatness. If you haven't read these books, I commend them to you.

4. ACKNOWLEDGMENTS

I thank the current Lord Rayleigh (great grandson of the famous scientist) for allowing access to the laboratory and other locations at Terling Place.

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ORIGIN AND EARLY ACTIVITIES IN ACOUSTICS AT THE TECHNICAL UNIVERSITY OF DENMARK

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ABSTRACT

Acoustic research and other activities at the Technical University of Denmark can be traced back to 1935, although it was not until 1966 that the university established an acoustical laboratory with new laboratory facilities of very high quality. The spark that initiated this development was the building of studios for the Danish Broadcasting 1931, that became an acoustical scandal and revealed the need for scientifically based knowledge on room acoustics and sound insulation. The rector of the Technical University, P.O. Pedersen, professor at the laboratory of telecommunication technique, started an acoustic research group in 1935, and he was the driving force in establishing a laboratory of sound technology in 1941. This was in the buildings of the Technical University, and some of the staff started to teach acoustics to the university students. P.O. Pedersen picked three young engineers for the acoustics research group: Vilhelm Jordan, Per Brüel, and Fritz Ingerslev. All three became of substantial importance for the development of acoustics in Denmark and worldwide; Jordan in concert hall acoustics, Brüel by establishing the B&K company, and Ingerslev as a professor at the university and a driving force in international cooperation (ICA, INCE) and standardization (ISO).

Keywords: *Laboratory facilities, Scale models, Room acoustics, Noise.*

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1. GREAT INVENTIONS AND BROADCASTING

1.1 The telegraphone and the arc-transmitter

Acoustics in Denmark started very early with exciting inventions. Already in 1898 technician Valdemar Poulsen (1869-1942) invented the ‘Telegraphone’ a magnetic wire recorder, which became the forerunner of the tape recorder. At the world exhibition 1900 in Paris Poulsen got the chance to record the voice of Emperor Franz Josef of Austria. This is believed to be the oldest surviving magnetic audio recording¹.

Only two years later in 1902, Poulsen and his assistant engineer Peder Oluf Pedersen (1874-1941) invented the ‘Poulsen Arc Transmitter’. This was widely used in radio before the advent of the vacuum tube technology. It may be at this time that P. O. Pedersen became interested in acoustics and later launched the early development of acoustics in Denmark. A comprehensive description of these inventions and their early applications can be found in [1].

1.2 The world’s first professorship in low-current electro technology 1912

P.O. Pedersen had graduated as a master’s in civil engineering, but through the close cooperation with Valdemar Poulsen, he became so interested in telecommunication that he picked up all available information about that by self-study. In 1909 he was employed at the Technical University² in Copenhagen in a newly established position as lecturer in telegraphy, telephony, and radio technology. In 1912 he was called to be a professor in the same field. This is

¹ https://www.youtube.com/watch?v=pzrB_pwi2TM

² In Danish, *Polyteknisk Læreanstalt* founded 1829 by H.C. Ørsted. The name was changed to *Danmarks tekniske Højskole* (DTH) in 1933 and to *Danmarks tekniske Universitet* (DTU) in 1994.

believed to be the world's first university Chair in low-current electro technology.

Two of the six students on the first course on low-current technology were Arnold Poulsen and Axel Petersen, who later invented a sound film system, in which sound was recorded on a separate filmstrip running in parallel with the image reel, patent 1923.

1.3 Broadcasting studios at the Royal Theatre

The Danish Radio was established in 1925 and had from the beginning a small orchestra for broadcasting of live music. However, there was a need for new and better studio facilities, and in 1931 such new radio studios were built in combination with a new stage for the Royal Theatre in Copenhagen. At this time there was little knowledge about acoustics, and an Austrian chemical engineer, Valdemar Oelsner, was engaged as he claimed to be an expert in acoustics. This was a great mistake. The sound insulation between the studios and the new theatre was insufficient, and the main music studio was designed with hard walls in the lower part and sound absorption in the upper part, which resulted in a pronounced flutter echo and tonal coloration. But Oelsner claimed that this was perfect [2]. Acoustically, the new studio was a scandal; Oelsner was dismissed from the project, and the case was reported publicly in newspapers and went on for several years, all the way to the High Court. This event was the spark that triggered very efficiently the awareness of acoustics in Denmark.

2. EARLY ACOUSTIC RESEARCH (1935-1953)

2.1 The first five years at LTT

The acoustical fiasco of the radio studios affected P.O. Pedersen so much, that he decided to start acoustic research activities, hosted at his Laboratory of Telegraphy and Telephony (LTT). Among the young researchers, that he employed for the work, were three men that became of decisive importance for the development of acoustics in Denmark:

- Vilhelm Lassen Jordan (1909-1982)
- Fritz Ingerslev (1912-1994)
- Per V. Brüel (1915-2015)

P.O. Pedersen published a report on the acoustical investigations 1935-1940 in the Laboratory of Telegraphy and Telephony (LTT) of the Technical University in Copenhagen [3]. The described activities were:

- Three original apparatus for the measurement of small vibrations in solid structures (constructions by Per V. Brüel),

- The new acoustical rooms of the laboratory,
- Four types of tube apparatus for the measurement of sound absorption at normal incidence covering the frequency range from 30 Hz to 20,000 Hz,
- The use of volume-resonators (Helmholtz-resonators) in room acoustics, and the practical application of such resonators to the acoustical regulation of a recently built auditorium,
- Room acoustical investigations in the scale 1/5 to 1/10 by means of the Poulsen-Telegraphone (Vilhelm L. Jordan).

The special laboratory rooms were two reverberant rooms (6*4*4 m) for measurement of airborne sound insulation of walls, one additional room (3*3*3 m) for measurement of impact sound insulation of floors, and an anechoic chamber. All surfaces of the anechoic chamber were covered with 19 layers of tissue, in total 84 cm thick. The free volume in the chamber had dimensions 4.14*3.70*2.40 m.

2.2 Jordan's early experiments with scale models

The idea of using scale models for room acoustic studies came from Germany, where Spandöck had used an Edison phonograph with wax drum to convert the sound from the natural frequency range into the five times higher frequencies in a 1:5 scale model. Jordan improved the technique by applying magnetic detection to a steel band in a Poulsen telegraphone. For Jordan's listening experiments were used speech or singing from a gramophone record. With a tape speed of 3 m/s, a sequence of 20 s was recorded on the telegraphone. Then the sound was played in the model room at a band speed of 15 m/s; at the same time, the tape was erased and the sound from a crystal microphone in the model room was recorded instead. In the model was used a crystal speaker or a small dynamic speaker, which allowed a frequency range up to 15,000 Hz equal to 3,000 Hz in full scale. However, there were problems with linear distortion and limited dynamics due to the rather high noise level of the telegraphone recordings. Jordan [5, p. 110] mentions the results of the listening experiments thus:

"In the untreated, weakly damped model, a very pronounced room effect is observed. Speech becomes completely incomprehensible, and the impression of the reproduced sound creates the illusion of a great space. Solo singing sounds like choral singing."

It was concluded that the method could hardly be used for finer analyses. It was not until much later in the 1990s that the idea of auralization was again taken up in connection with room acoustic computer models.

2.3 Concert hall acoustics as a spin-off

By the intervention of P.O. Pedersen, V.L. Jordan continued working with full scale concert hall acoustics in the concert hall (Studio 1) that was being built for the Danish Radio 1940-1945. Especially the acoustical connection between stage and auditorium had his attention. After 1945 he started as a consultant, and the first project was a new concert hall for the Tivoli Gardens in Copenhagen (1950-1956).

The cooperation with the architect Jørn Utzon on the famous Sydney Opera House is probably the first major example of a modern concert hall, where the basic design and many details have been radically influenced through acoustic studies in scale models [9, p. 100]. In the opera hall, work was done on the balance between measurements of early reverberation on stage and in the hall, and the balance between a sound source on stage and in the orchestra pit. It was a very lengthy project, starting after the architectural competition in 1957 and continuing until the opening of the opera house in 1973. The architect changed the project several times, and four quite different designs of the concert hall were tested in 1:10 scale models.

During these years, there was a significant development of the acoustic measuring technique with better spark source, better and much smaller microphones, and the telegraphone was replaced by the tape recorder with magnetic tape. Equally important was the parallel development of room acoustic parameters and criteria for objective assessment of concert hall acoustics, and here V.L. Jordan contributed actively: Rise Time 1959, Steepness 1965, Inversion Index 1968, Early Decay Time 1969, Room Response 1976.

Due to the very long process in Sydney, experience was gathered in the meantime from several other large projects, where Jordan used and further developed the modeling technique. One of these projects was the Metropolitan Opera House in New York with 3800 seats, designed in the years 1959-1966. For several decades, V.L. Jordan and his son, Niels Jordan (1941-2017) did the acoustics of many concert halls all over the world, in many cases using scale models for the acoustical analysis of the design.

2.4 The Acoustical Laboratory 1941

P.O. Pedersen became director of the Technical University in 1922 and from 1933 he was rector of the same. In 1937 he was involved in the establishment of the Academy of Technical Sciences³, which was a kind of umbrella organization for various technical institutes that should provide testing and other kinds of assistance to the Danish industry and authorities. This was hard times for the country eco-

nomically, and the only possibility for expanding the activities at the technical university was massive financial contributions from the Danish industry. P.O. Pedersen succeeded with this, and one argument was, that Denmark has no raw materials, so instead it was important to increase the skills, both in knowledge and production.

One of the first ATV institutes was an Acoustical Laboratory⁴ established 1941. This laboratory was hosted at the Technical University, and directly related to LTT. The scientific staff of the institute should also teach acoustics to the students at the university. Fritz Ingerslev became the head of the Acoustical Laboratory from the start in 1941. The acoustical activities in the following six years are described in a report [4] under the following headlines:

- Descriptions of the laboratories
- Sound pressure, loudness, and frequency analysis of airborne sound
- Mechanical vibrations
- Reverberation time
- Sound distribution
- Sound absorption coefficient measured by the tube- and the room-method
- Sound insulation against airborne sound
- Attenuation of impact sound
- Electroacoustic measurements
- Annex: Short description of the electrical measurement apparatus.

The work on sound absorption led to two doctoral theses⁵, one by V.L. Jordan [5] and another one by P.V. Brüel [6].

Concerning impact sound measurements, a tapping machine was constructed in the laboratory in agreement with existing American and German standards. Measurements were made in the unit of phon, using a sound level meter with weighting curve B.

Asger Kjerbye Nielsen had been working in the laboratory with resonators and theoretical models for slits and holes. He made a doctoral thesis on the reciprocity method for measurement microphones [7].

The teaching activities of the laboratory were directed towards students in building technology as well as in electro technology. Ingerslev became associate professor at LTT in 1943, and he wrote the first textbook on building acoustics in 1944, published five years later [8].

³ In Danish, *Akademiet for de tekniske Videnskaber* (ATV)

⁴ In Danish, *Lydteknisk Laboratorium* (LL)

3. THE NOISE PROFESSOR (1954-1982)

3.1 International cooperation

Fritz Ingerslev was a fiery soul and soon he took up the fight against noise, and this became his lifelong mission. In 1953 he defended his doctoral thesis (on loudspeakers) and the following year he became professor in low-current electronics at the LTT department, see Fig. 1. Still, he continued as head of the Acoustical Laboratory.



Figure 1. Fritz Ingerslev in his office around 1960. The portrait on the wall is of Valdemar Poulsen.

His international engagement was pronounced, and in 1954 he was the driving force in creating the Nordic Acoustic Association as a forum for connection between acousticians in the Nordic countries. However, only Finland and Sweden had already an acoustical society, so it was a little premature. Norway and Denmark established their national acoustical societies in 1956.

Already in 1951, Ingerslev became a member of the board of International Commission for Acoustics (ICA), a position that he kept until 1969. The main activity of this commission was to arrange international conferences on acoustics, which should be every third year. So, Ingerslev became the chairman of the fourth ICA in Copenhagen, a great success with 1200 participants, 300 presentations in nine parallel sessions and 15 invited plenary lectures. One of the challenges – long before telefaxing and internet – was a demand from UNESCO that there should be three official languages: English, German and French, and the presentations could be given in any of these languages.

3.2 The Acoustics Laboratory 1963

Since 1957 Ingerslev was a member of a committee at the technical university that should outline the future needs of the electrical engineering sector. The background was that the buildings in central Copenhagen had become insufficient and without possibilities for further expansion. In 1960 it should be decided to move the technical university to a new campus area North of Copenhagen. Acoustical facilities of the highest possible quality were included in the plans. It was probably of decisive importance that Ingerslev gave a distinguished lecture on acoustics at an annual celebration at the technical university, attended by people with good connections to politicians with influence on the necessary decisions. His passionate talk must have been very convincing.

The new acoustic facilities included two anechoic chambers (1000 m³ and 60 m³) and four reverberation chambers (around 240 m³) for the measurement of acoustical properties of building materials and constructions [11].

In connection with the movement to the new campus, the technical university established 1963 a new department, the Acoustics Laboratory⁵. The older ATV-institute, the Acoustical Laboratory, moved into the same building, and some of the staff were transferred to the new university department. In the following years, Ingerslev was the head of both laboratories (LA and LL) sharing the facilities. While the new LA should do teaching and research, the working field of LL was to do measurements and give advice to the government and the industry.

3.3 ISO and I/INCE

In 1961 professor Ingerslev became aware of the possibilities associated with international standardization, and he asked the Danish Standardization Organization (DS) to establish a formal membership of the technical committee ISO/TC 43 Acoustics. In the following years, several working groups were established with Ingerslev as convener and new standards were made concerning measurement of noise from vehicles and airplanes. Two subcommittees were made in 1968, SC 1 Noise and SC 2 Building Acoustics, and Ingerslev was appointed chairman of SC 1 with secretariat hosted by Danish Standard. Shortly after the same happened with the secretariat of the general acoustics committee TC 43. This development says something about Ingerslev; how dedicated and efficient he was, and highly respected among international colleagues.

⁵ In Danish, *Laboratoriet for akustik* (LA). The name was changed to Department of Acoustic Technology in 1995.

In the USA was established an Institute of Noise Control Engineering (INCE) with the purpose of arranging meetings dealing with noise problems, and Ingerslev followed this initiative closely. The first Inter-Noise conference was held in the USA 1972 and already next year, the second Inter-Noise conference was held in Denmark with Ingerslev as chairman. After this success, he became co-founder and chairman (1974-1988) of the International Institute of Noise Control Engineering (I-INCE), coordinating the Inter-Noise conferences held all over the world every year.

The subtitle of the second Inter-Noise conference was “Noise is a sneaking poison”. This was meant to emphasize the seriousness of the fight against noise in workplaces, in homes and in the environment. Ingerslev used the press to spread information about the event and to pay attention to noise problems among engineers and politicians; he wanted to wake them up!

3.4 The fight against traffic noise

Traffic noise came in the focus in the 1970s, and through his use of the press, Ingerslev became famous as the noise-professor. When the government established a ministry of the environment, he arranged a meeting with the minister to explain the importance of noise. The press was informed about the meeting, and the newspapers could bring an article with a photo of the noise professor meeting the minister. Ingerslev was a master of “political acoustics”.

So, even politicians were listening to Ingerslev when he had something to say. One example is the plan for a four-lane motorway that should lead the traffic into the center of Copenhagen along the lakes surrounding the old city center; however, Ingerslev’s protests managed to stop this.

Founding was raised for an ambitious PhD project for the psychologist Else Relster, who should study the effects of traffic noise with Ingerslev as supervisor. He involved the Acoustical Laboratory to do measurements of noise exposure of dwellings that were selected to be either with high or low traffic noise levels. Else Relster did 960 interviews and was able to establish a dose-response connection showing the decrease of wellbeing with noise levels exceeding 55 dB⁶. The measurements and interviews were made under ideal conditions as early as 1972, i.e., before it became common to apply special sound insulating windows in areas with high noise exposure.

3.5 The vision for the Acoustics Laboratory

Since 1974, the Acoustics Laboratory has made annual reports describing the activities in teaching and research. In

the first years, the acoustical areas in which the laboratory had research and teaching, were outlined as follows:

- Aeroacoustics (outdoor sound propagation)
- Fundamental acoustics and measurement technique
- Bioacoustics, physiological and psychological acoustics in relation to humans and animals
- Building acoustics
- Electroacoustics
- Mechanical vibrations
- Musical acoustics (musical instruments)
- Room acoustics
- Noise

In addition, was mentioned ultrasound and underwater acoustics as areas in which the laboratory was not active. Some of the research activities were in close cooperation with the Acoustical Laboratory under ATV, which was also headed by Ingerslev and located in the same building.

For historical reasons, the Acoustics Laboratory was established under the electrotechnical faculty. However, from the very beginning it was clear that research and teaching activities should include the relevant areas of building engineering and mechanical engineering.

Thus, in 1975 the faculty of building engineering agreed to establish both a lecturer and a professorship in building acoustics, assigned to the Acoustics Laboratory. Jens Holger Rindel was employed to teach building acoustics, but when professor Ingerslev was asked to be a member of the committee that should evaluate the applicants for the professorship, he refused, because he considered applying himself. The position was never announced, and Ingerslev was called to be professor in building acoustics. Then, what should happen with Ingerslev’s former professorship in low-current electro technology? It was clear that it should be in acoustics, but it turned out to be more complicated than anyone had expected.

Leif Bjørnø (1937-2015) became the new professor in acoustics in 1978. He had a background in mechanical engineering, and he was particularly interested in ultrasound and underwater acoustics. Thus, ideally this would complete the vision of covering all aspects of acoustics. However, the cooperation with the other members of the academic staff in the Acoustics Laboratory was difficult, and gradually became worse. In 1982, professor Bjørnø’s research group for Industrial Acoustics moved to another department under the faculty of mechanical engineering. He left DTU in 2000. The very successful research group on digital signal processing (DSP) moved in 1987 from acoustics to join another department with a focus on DSP within the Institute of Electronics.

⁶ $L_{A,eq,24h}$ in free field.

When Fritz Ingerslev retired in 1982, his professorship in building acoustics was not opened for a successor. In 1990 Jens Holger Rindel was promoted to professor (docent).

4. COOPERATION WITH INDUSTRY

4.1 Measurement microphones and metrology

Microphone calibration was an important activity since the early work of Kjerbye Nielsen [7]. At the Acoustics Laboratory this was headed by Knud Rasmussen, who managed to get several international grants and projects under the European Community Bureau of Reference (BCR) and the European Metrology Networks (EUROMET). In collaboration with B&K, the Danish reference laboratory was located at DTU from 1989.

4.2 Outdoor sound propagation

Sound propagation over terrain was a research field of great importance for calculations models in relation to traffic noise and noise from industrial plants. At the Acoustics Laboratory this was taken up by Karsten Bo Rasmussen, who did scale model experiments for verification of advanced theoretical models. He defended his Dr. Techn. Thesis on this subject in 1991. However, in 2000 he left DTU to join the research center for hearing aids at Oticon.

4.3 Psychoacoustics and hearing aids

Since the establishment of the Acoustics Laboratory in 1963, Ole Juhl Pedersen was a driving force in the field of acoustic communication. His teaching together with Torben Poulsen has formed the basis of several psycho-acoustical and audiological MSc- and PhD-projects as well as national and large international research projects often in cooperation with industry. Among them were the audiological ODIN project, a research cooperation between the three large Danish hearing aid companies. Without the industry that employed all these candidates, psychoacoustics would not have had such success – and vice versa.

4.4 Loudspeakers

The good acoustic research facilities at DTU were basis for the EU-project Archimedes under the framework of EU-REKA (with Bang & Olufsen in Denmark and KEF in England). This was on the sensation of sound quality of loudspeakers. This involved room simulations in the anechoic chamber, see Fig. 2, and the building of a new IEC listening room in 1989.

The following 'Lo-dist' project was on audibility of distortion in loudspeakers. Optimal acoustic quality was also the

goal for another set of scientific investigations on perceived sound from loudspeakers made by B&O (Søren Bech) in cooperation with Danish and international universities. These projects ended up both with inventions and new state-of-the-art loudspeakers.



Figure 2. Set-up in the large anechoic chamber for the Archimedes project in 1988.

4.5 Concert halls and musicians

Architectural acoustics and in particular the field of room acoustics was given more weight after 1975. The acoustics of concert halls from the musicians' point of view became one of the new research areas, with pioneering work on stage acoustics by Anders Christian Gade (1982) and Graham Naylor (1987). Measurement campaigns were made measuring acoustical parameters in concert hall, first in Denmark and then in some of the best halls in Europe. This research activity led to a project supported by the Danish Radio, namely, to solve the acoustical problems in the DR concert hall from 1945, see section 2.3. In 1989 the concert hall could re-open with significantly improved stage-acoustics including reflector panels designed in accordance with new research results.

4.6 Room simulation and auralization

Sound fields in rooms was one of the main research fields of Finn Jacobsen. In 1984 Rindel initiated the development of computer simulations of sound in rooms, with the vision to include auralization. With various external funding, the work was started with Asger Donovan, and continued by Graham Naylor. The program was named ODEON and launched for commercial distribution in 1991. The same year, an international symposium on room acoustic simulation and auralization was organized by Rindel, Naylor and Mendel Kleiner from Chalmers Technical University in Sweden. The work with the room acoustic simulation tool and auralization was continued with Claus Lynge Christensen, and in the following years it became the basis for several related research projects headed by Rindel, including the spectacular EU-projects CHARISMA on Byzantine churches and Sinan's mosques and ERATO on Roman theaters and odea. The connection between musical instruments and rooms was the topic of the EU project DOREMI and the first multi-source auralizations of a symphony orchestra were made with ODEON in 2005. In 2008, Rindel left DTU, and the Odeon company moved to its own premises at the DTU Science Park.

4.7 Noise from machinery

Noise in ships, and structural noise from diesel engines were studied by John Ødegaard at DTU from 1972 using scale models (1:5). This research field was continued by Mogens Ohlrich, and from a long list of projects can be mentioned noise from wind turbine towers (1985) and interior noise in helicopters (RHINO, 1995). The EU project FANPAC was on noise from turbofan engines (1996).

5. THE INTERNATIONAL PERSPECTIVE

5.1 Shift of focus from teaching to research

The first years after 1963, when the Acoustics Laboratory was established, the academic staff had a strong focus on teaching activities, and during the 70's and 80's the lecture notes for the various acoustic courses were constantly improved and brought to a high level of quality, although in Danish. In these years, research was published in reports, only. There was no tradition at the Acoustics Laboratory for publishing research results in the international scientific journals. Around 1990 things changed, because there was an increasing demand to the academic staff to publish in peer-reviewed journals, see Fig. 3. Finn Jacobsen was particularly efficient in writing

scientific papers for journals, which was inspiring for his colleagues.

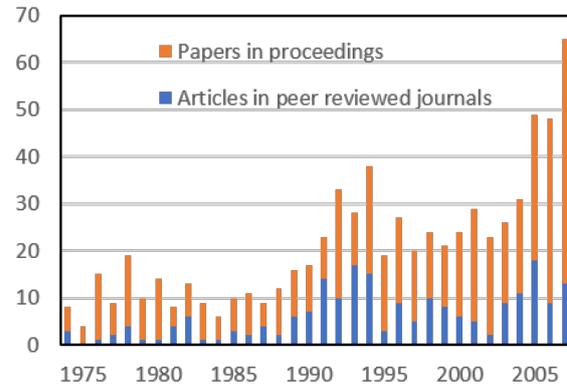


Figure 3. Number of scientific papers per year.

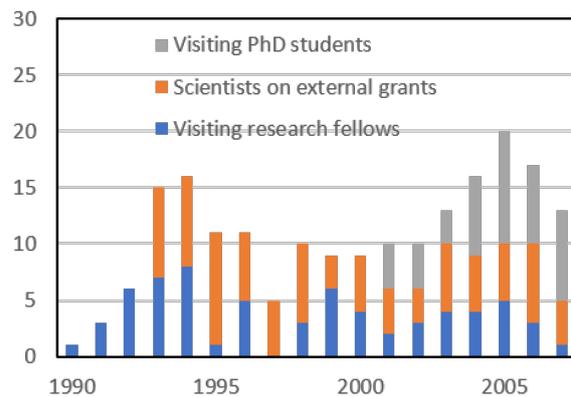


Figure 4. Number per year of visiting research fellows, scientists on external grants, and PhD students.

5.2 Visiting researchers

Around 1990 the approach to research became more international, and with various types of grants it was possible to receive or invite research fellows and other scientists for longer stays at the Acoustics Laboratory, see Fig. 4. From 2001 this also included PhD students from foreign universities. Severe budgetary problems for the university appeared in 1997, and 7 % of academic staff at DTU had to leave. However, due to very favorable rating results, none of the academic staff at the Department of Acoustic Technology

were affected. This year, the department received 77 % of the total budget from industry and national and international grants.

Jean-Dominique Polack was appointed professor in electroacoustics 1999. However, only two years later he decided to leave and return to France, where he had his family. Although his wife was Danish, she was not willing to give up her job in Paris.

5.3 International MSc in Engineering Acoustics

A decreasing number of Danish engineering students was becoming a problem for DTU in 1998. At the same time the Department of Acoustic Technology experienced an increasing internationalization that called for lectures and lecture notes in English. A new international two-year MSc program in Engineering Acoustics was launched in 2000. From then on, all courses in acoustics were given in English because many students from abroad attended the courses. This turned out to be a great success, and the number of highly motivated foreign students in acoustics more than compensated for the lack of Danish engineering students at this time (half of the students on acoustics courses were from abroad in 2000). Every year, 12 new MSc students were accepted for the program. In this way, the section of Acoustic Technology avoided reductions in the scientific staff. However, it was hard times for the university.

A new structure of DTU in 2000 meant fewer but bigger departments. Department of Acoustic Technology became one of five sections in Ørsted-DTU, a big department of electro technology. In the annual report for the year 2000 is stated that a major challenge is facing the section of Acoustic Technology in the coming years:

“Acoustic Technology shall have to redefine areas of excellence and converge toward a few specific areas where collaboration within the section, with industry, and with other institutions both in Denmark and abroad, can achieve critical mass.”

It is not clear what is meant by critical mass, but obviously the former vision, that the department should cover all relevant aspects of acoustics, is no longer valid.

5.4 New research centers related to acoustics

Thanks to massive financial support from the Danish hearing aid industry, the acoustical activities have expanded immensely after 2000. In 2003 was established the Centre for Applied Hearing Research (CAHR). The purpose with CAHR includes promoting research and education on acoustical communication hearing impaired peoples' listening capabilities and the use of auditive models in hearing aids. Impressive results are achieved due to exchange of

knowledge, where cooperation between common university research and industrial development goes hand in hand. In 2013 The Oticon Centre of Excellence for Hearing and Speech Sciences (CHESS) in which connection new research facilities has been built as extensions to the original laboratories. In 2014 the Centre for Acoustic-Mechanical Micro Systems (CAMP) was established, connected to the Acoustic Technology section under the Department of Electrical and Photonics Engineering.

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DANISH PIONEERS AND COMPANIES IN ACOUSTICS WITH A FOCUS ON DR. BRÜEL

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ABSTRACT

This paper is about the early part of the history of the Acoustics in Denmark. It is based on previous anniversary writings, the author's interviews with Dr. Brüel and Brüel's own notes "Episodes and Achievements within Acoustics before 1954". Starting with the invention of the "Telegraphone" in 1898 and other early acoustical inventions (loudspeakers, sound film, radio production), the paper will concentrate on Dr. Brüel and the company he established in 1942 with Dr. Kjær (B&K). The acoustical instrument development took its early start with the world's first frequency analyzer with constant relative bandwidth (1940) - where B&K's iconic light-green front plate was seen for the first time. Some background story for Dr. Brüel's multifaceted effort in acoustics will be revealed, e.g., his work with the acoustics in the new building for the Danish Radio (1941), his work with sound absorbers and university activities in Sweden during WWII (1942) and the doctoral thesis "Use of the standing wave-method in Acoustics" (1944). The early groundbreaking instruments from B&K include: The tapping machine (around 1945), the level recorder (from 1943 and on), the pistonphone (around 1950) and the condenser microphones (1950; 1955). Finally, the Danish hearing aid companies and loudspeaker companies will be mentioned.

Keywords: *Acoustical inventions - Measurement instruments*

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1. INTRODUCTION

When the Danish Acoustic Society (DAS) was to celebrate its 50th anniversary in 2005, it was only natural to involve Dr. Brüel – co-founder of Brüel & Kjær and of DAS - in the anniversary publication [1] that was being prepared. Through this work, the author had the opportunity to interview Dr. Brüel and write a summary of Brüel's own notes: "Episodes and Achievements within Acoustics before 1954" [2]. It became clear that here was an interesting and almost forgotten story which from around 1930 formed part of the foundation for the development of the acoustic field in Denmark.

But it all started long before with some important Danish discoveries and inventions in the field of low-current electricity: The fundamental discovery was the Electromagnetism (1820) by Hans Christian Ørsted¹. Later came the "Telegraphone" – forerunner of the tape recorder (1898) by Valdemar Poulsen² and the "Poulsen Arc transmitter" – for wireless transmission (1902) by Valdemar Poulsen and Peder Oluf Pedersen³.

New companies were started such as Nordic Film in 1906 and radio production at Bang & Olufsen (B&O) in 1925 – both still in action. Same year the first Danish sound film recorded indoors was shown in Copenhagen. Danish Broadcasting (now Danish Radio, DR) started in 1925 and this helped to kick-start the development of the Danish loudspeaker industry⁴.

¹ H.C. Ørsted (1777-1851), physicist and chemist, 1817 Prof. at the Copenhagen University, 1829 founder of the *Polytekniske Lærestanstalt (PL)* – now *Danish Technical University (DTU)*.

² V. Poulsen (1869-1942), engineer and inventor.

³ P.O. Pedersen (1874-1941), 1912 Prof. in low-current electro technology, 1927 Author of the internat. recognized reference-book *The Propagation of Radio Waves...*, 1933 president at PL.

⁴ Including the large companies Peerles, Vifa and Dynaudio (drivers) as well as JAMO and DALI (speaker systems) – also co-operating and with a common research project at DTU.

Although the period includes WWI, it was a time of progress and “electrotechnics was the new subject that met the challenges through applications in radio and movies; areas that were going to get great scientific, social, and economic importance. The foundation of the Acoustical Society of America already in 1929 reflects this aspect” [7].

1.1 Acoustic research activities also in Denmark

In fact, a project that went completely wrong was among the reasons why P.O. Pedersen⁵ in 1935 started the first acoustic research activities at the Laboratory of Telegraphy and Telephony (LTT) at Polyteknisk Lærestanstalt (now DTU) and became thereby “The source of Danish Acoustics”. In the following years international scientific exchange was growing both in Europe and in the USA. One of P.O. Pedersen’s most interested students was Per Vilhelm Brüel.

2. PER VILHELM BRÜEL

Per Vilhelm Brüel (1915-2015) was born in a forester family, but his interests were in the technical field [3]. Already as a young boy Brüel built a crystal radio and later, aged 14, he read with interest an article about radio and electromagnetic waves [2]. The author was Professor P.O. Pedersen, who many years later would become Brüel’s mentor. At LTT Brüel met Viggo Kjær and they became friends. Soon they decided that they wanted to start something together. In 1939 they both got their MSc degrees studying several extra months including the summer holidays. Brüel’s technical skills quickly showed themselves when he as part of his MSc assignment constructed a “photocell amplitude meter” when he should measure the oscillation amplitude of a wall. This apparatus is described in the publication by P.O. Pedersen [4], see Figure 1. The first part of this publication is written by Brüel, but his name was not on the cover, which somewhat disappointed the ambitious Brüel. Even though it was a natural consequence of P.O. Pedersen being the leader of the laboratory it bothered Brüel for many years. Nevertheless, it has not diminished Brüel’s respect for his professor. As Brüel tells “I owe him a lot”.

⁵ See more information in the FA2023-paper “Origin and early activities in acoustics at the Technical University of Denmark” by J.H. Rindel and C.M. Petersen.

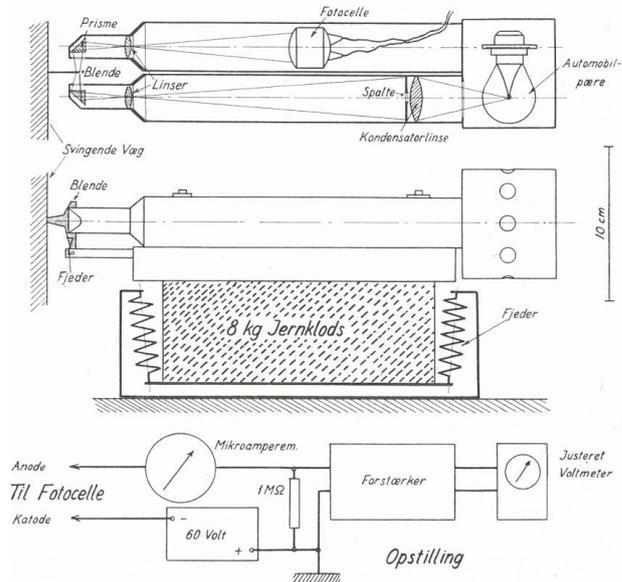


Figure 1. Brüel’s photocell amplitude meter [4]

Brüel became P.O. Pedersen’s assistant, and he suggested that Brüel should work on writing a doctoral thesis – a suggestion he liked very much. The thesis was supposed to be about using the Standing Wave Tube (SWT) to measure the complex acoustic impedance (and sound absorption). P.O. Pedersen would seek funding for 1½ years employment at LTT to carry out this work.

In the autumn of 1939 Brüel was drafted to the Danish army and started serving as dispatch rider driving motorbike all around Denmark. Later he was transferred to the Army’s radio workshop at the headquarters in Ryvangen, Copenhagen. Here the work was about radio transmitters – and then Brüel was back on track as scientist and engineer.

2.1 Brüel’s story up to 1943

In 1939 the last issue of JASA, the Journal of Acoustical Society of America, came to Denmark before the WWII closed the connection with the outside world. In this both Brüel and Kjær read about a selective amplifier in which the selective part was an amplifier with a double T-joint in a feedback loop. This principle had to be useable in an acoustics analyzer where the bandwidth would be proportional with the frequency. In his spare time at the Army’s radio workshop in Ryvangen, Brüel started experimenting with what was to become a brand-new invention: The world’s first acoustics analyzer with constant relative bandwidth. It was finished in February 1940 and is shown at Figure 2

with typical military instrumental look and a characteristic light green color at the front plate – a color which later became a distinctive feature of a whole production of high standard acoustic measuring instruments.

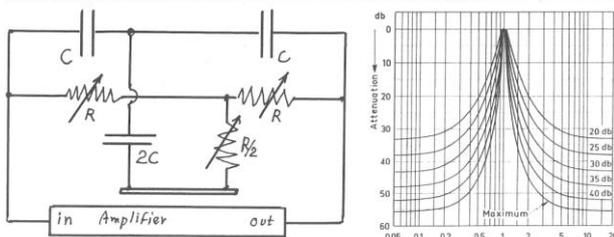
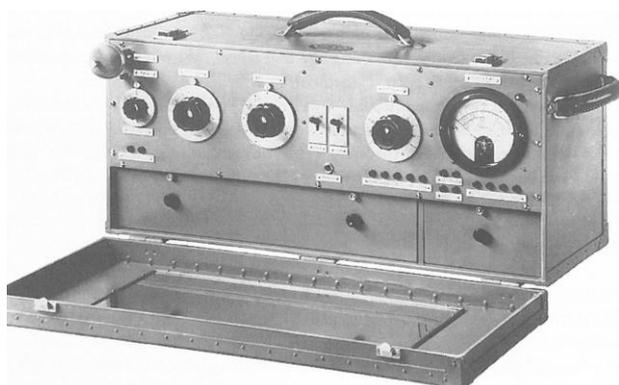


Figure 2. The world's first acoustics analyzer with constant relative bandwidth [3]

Due to the German occupation, it was decided to demobilize all drafted personnel in the Danish Army and therefore Brüel had plenty of spare time to make plans together with Kjær for their future company. They added line powering instead of battery powering at the frequency analyzer.

Both Brüel and Kjær got new jobs in the following year, 1941. Kjær at radio manufacturers. Brüel who worked on his doctoral thesis was – again thanks to P.O. Pedersen – engaged as assistant to Prof. Nøkkentved⁶ who was responsible for the building engineering at the new Radio house under construction for the Danish Broadcasting (now Danish Radio). The work consisted, among other things, of tuning the reverberation times in the studios which went incredibly well with Brüel's competences from the work at LTT and his doctoral thesis. The engagement at the Radio house ended in late 1942, but before that a director from a Swedish glass-wool factory, Höganäs, had visited the new

⁶ Christian Nøkkentved (1892-1945), 1932 Prof. in building statics at *Polyteknisk Lærestalt* (now DTU).

Radio house and he and Brüel had a good meeting about acoustic absorbers with glass-wool. This was the start of Brüel's work in Sweden⁷ developing different types of absorbers among others resonance panels with holes. In 1943 he was offered a job as a part time associate Prof. at Chalmers University of Technology in Gothenburg – bound until 1947. Here Brüel became head of the acoustical laboratory which i.a. had 12 academic refugees employed.

2.2 Brüel's doctoral thesis, 1944

Brüel's work with his doctoral thesis included results from the new Radio house and was finished at the end of 1944. One of Brüel's graphs showing the translation of normal incidence absorption (from SWT measurements) to random incidence (from a reverberation room) is shown in Figure 3. When Brüel should defend his doctoral dissertation⁸ at PL in Copenhagen it almost went wrong. Brüel came from Sweden and at the Danish border the German soldiers were in an evil temper and ripped through all his papers and tossed them into the air without finding anything – and then they tore off the heels of his shoes. So Brüel defended his doctoral dissertation wearing shoes with glued-on heels. He got his scientific degree Dr. Techn. – and hereafter he mostly was addressed as "Dr. Brüel".

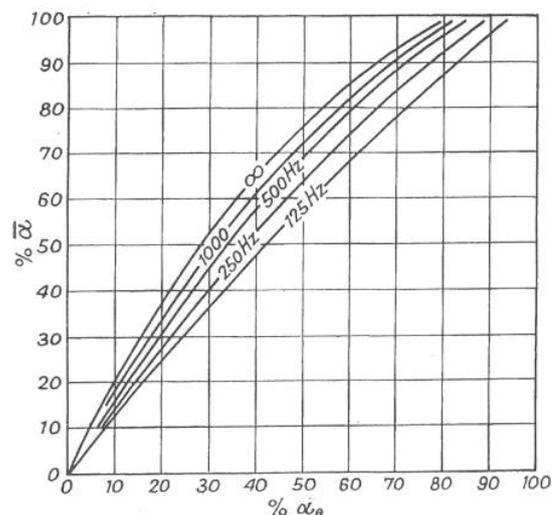


Figure 3. Normal incidence absorption (x-axis) versus random incidence (y-axis) [2]

⁷ The problem of crossing the country border in wartime Brüel solved using a previous job relationship with the Danish water treatment specialist Kryger A/S to obtain a visa.

⁸ The official title was "*Rørmetodens anvendelse i akustikken*" (Application of the tube method in acoustics).

2.3 Brüel's further carrier

Brüel was very committed to the professional acoustical environment and in 1944 he co-founded the Swedish Acoustical Society (SAS) – 10 years before he co-founded the Danish Acoustical Society (DAS). In addition, he was a highly respected international knowledge-based salesman who also had a seat in numerous standardization committees and led the way in new technologies. In [3] Brüel is described as charismatic, adventurous, full of ideas, expert craftsman, clever negotiator and able to express complex subjects verbally and on paper in an understandable way. Besides, Brüel had a flight certificate⁹ for both propeller planes and turboprop planes, and B&K itself had such planes in the "B&K Airline" (1963-1992), where he was the chief pilot. Brüel was personal friend with the famous American acoustician Dr. Leo L. Beranek (1914-2016) since 1950 and the Chinese professor Maa Daa You (1915-2012). The latter he met in 1953, when Maa acted as interpreter for Brüel who during two weeks held 10 lectures on acoustics for 300-500 listeners at the university in Beijing. Both Beranek and Maa did their doctoral thesis's at Massachusetts Institute of Technology (MIT), Boston. The three often met and because they were almost the same age, every 10 years they celebrated their round birthdays together at festive gatherings. Brüel and Beranek lived to be 100 years old.

As Beranek writes in [3]: "A major reason for the success of B&K was the unusual marketing efforts of Brüel, who seemed to be everywhere at once – in the USSR, Europe, North America, China".

3. THE COMPANY BRÜEL & KJÆR

In 1942 the company Brüel & Kjær obtained an official license to operate. Even though they started with a small production and a few employees from the Army's radio workshop the first year, they sold to the Nordic countries and got some good connections to the acousticians there.

3.1 The first years

During the first five years when Brüel was busy in Sweden and Kjær worked at different Danish radio manufactures, the activity level of the company was rather low. Not least because of WWII which made it difficult to get materials and components. After just a few years, the level recorder (1949, see section 4.2) really opened the world market and

⁹ For 43 years – until he was 85 Brüel flew approx. 18.000 hours and had 7.000 landings mainly in Europe.

several other instruments also contributed, especially the measurement microphones (1955, see section 4.4). B&K's instruments were known as second to none and in the following years, the company was the world leader in acoustic instruments.

3.2 A successful company

Among the many well-known later instruments are accelerometers, sound level meters, digital frequency analyzers (1/1- and 1/3-octave bandwidth as well as narrowband) sound intensity and one of Brüel's favorites, the RASTI-system measuring Rapid Speech Transmission Index. The company had many highly skilled experts in each of their fields of expertise and attracted many talented electro-acousticians from all over the world. B&K grew steadily and peaked in 1990 with approx. 4000 employees worldwide and annual sales from Danish companies of Euro 124 million [3]. The complete story is that after the peak came hard times and in 1992 the company was sold at the same time as the founders left. The company was split into several separate companies and Brüel & Kjær Sound & Vibration ended up in HBK, Hottinger Brüel & Kjær in 2020 as the continuing company for the core sound and vibration market (2021: 425 employees, revenue Euro 90 million).

3.3 Viggo Kjær

Viggo Kjær¹⁰ (1914–2013) was Brüel's companion and co-founder of B&K. In [3] Kjær is described as shy, soft spoken, brilliant engineer and designer, meticulous attention to detail, cost-conscious to an extreme, encyclopedic knowledge of everything he considered important and always highly respected. Even though Kjær received an honorary doctorate he always was addressed as "Mr. Kjær".

4. GROUNDBREAKING B&K INSTRUMENTS

In the following, only a few of the early B&K instruments will be described in detail based on [1], [2] and [3].

4.1 The tapping machine (around 1945)

At Chalmers University of Technology in Gothenburg they worked intensively with noise problems in wooden houses and many measurements of footsteps from floor separations were performed. It was therefore necessary to have a structural sound source which, with a sufficient

¹⁰ V. Kjær, 1939 MSc, 1974 honorary doctorate from the Danish Technical University (*For significant efforts to promote electronic research as a basis for industrial production of measuring instruments*).

signal-to-noise ratio, could simulate walking/trampling people. Brüel reports [2] that they had heard of experiments in Germany, where they tapped repeatedly with a 500 g hammer on the floor separation and measured the noise level below with a correction for room absorption. Actually, there was already in 1936-1937 [9] a German proposal for a tapping machine, which has technical specifications that were later adopted in the standard ISO 140. Brüel's contribution was to improve the mechanical construction of the tapping machine when he and his team constructed the hammer mechanism, in which five hammers of 500 g sat close together, and each hammer fell 40 mm twice a second. The machine was manufactured in five copies so that colleagues in Norway and Finland could also test it, see Figure 4.

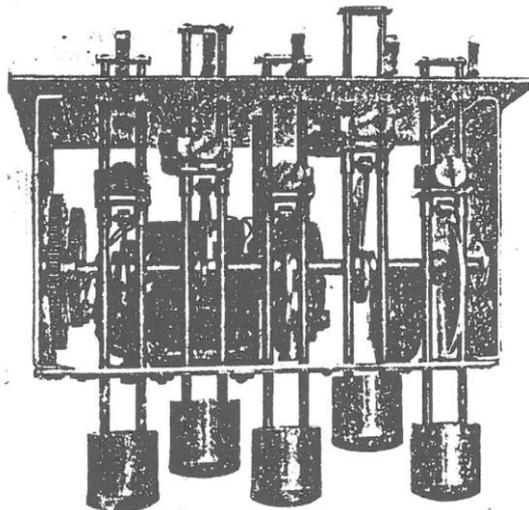


Figure 4. Prototype tapping machine [2]

Shortly after the war approx. 1945, the IEC (International Electrotechnical Commission) wanted to standardize such a machine. Brüel heard about it, and on his own initiative he forwarded drawings and descriptions and went to a meeting at IEC in Switzerland with the machine under his arm. The plan for the machine was to be produced in Denmark. The machine was approved with the minor adjustment that the distance between the hammers had to be increased. The final version of the tapping machine is shown in Figure 5.

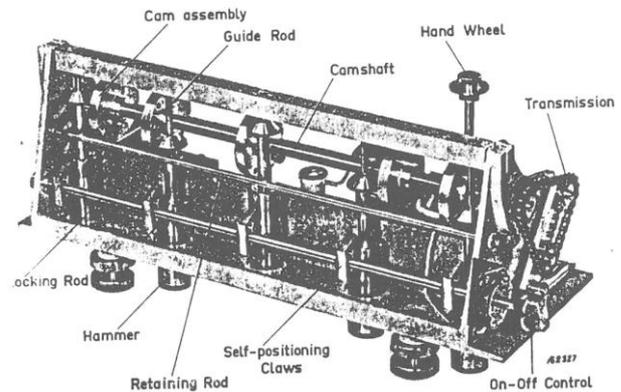


Figure 5. Tapping machines (B&K's model) [2]

It is with tapping machines according to this principle that in most of the world right up until 2015¹¹ standardized impact sound measurements exclusively were carried out (cf. ISO 140-7). In this way, Brüel came to play a decisive role in the standardization of the tapping machine.

4.2 The level recorder (after 1943; 1949)

Already in 1942-43 there was a great need for level recorders with logarithmic recording of the decay of the sound pressure level to determine the reverberation time in a room. It was supposed to replace Neumann's recorder, which Siemens stopped production of at the start of WWII. Brüel and his staff developed an entirely new type of level recorder based on an electrodynamic system with magnet, coil, relief arm and recorder pin as well as some stretched wires. At first there was doubt as to whether there was a sufficient market for these level recorders; Kjær believed that only 50 could be sold, which was too few. Brüel therefore had to produce the first examples in Sweden. Later, B&K in Denmark started the production – and the level recorder turned out to be extremely successful. During 30 years, 25.000 units were produced – according to Brüel especially because the acoustic world had a great need to be able to make reverberation curves and because this level recorder did not have the faults of its predecessors (wear and inertia). After 1949, Kjær improved the level recorder with an extra coil outside the drive coil, which made the printer very fast and precise. The B&K level recorder created a sensation among acoustical professionals – never before had sound pressure level in decibels been measured as

¹¹ From 2015, impact sound measurements with a heavy rubber ball were also standardized (cf. ISO 16283-2).

a function of time. Better yet it included a pen system for recording. But perhaps the most important success parameter was that the company's management knew the product's use and could discuss it with the customers, which included all important institutions and people in the area. Brüel himself says in [2] that "there is no doubt that this level recorder, in addition to being a good business, has also greatly increased Denmark's position as the country where people know something about acoustics". It was also the level recorder which, in a ½-page article authored by Brüel and Uno Ingård in JASA 1949, opened the market for B&K in both the USA and Japan. Also, the communist countries were interested. See Figure 6 for the headline of the JASA article and the 1949-version of the level recorder.

A New High Speed Level Recorder

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(Received October 11, 1948)

A high speed level recorder of the "potentiometer type" which is useful both for laboratory and field measurements is described. The recording system consists of a moving coil with translational motion, the speed of which can be varied with a maximum value of about 1000 db/sec. Recording is made by a steel stylus on waxed paper of the same kind as that in the usual Neumann recorder.

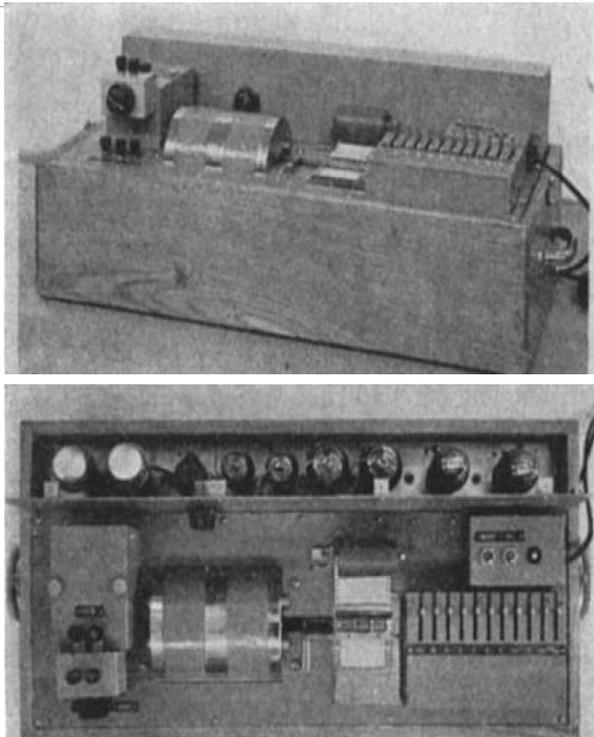


Figure 6. From the JASA article, vol. 2, no. 2, 1949

From the USA Dr. Leo L. Beranek and from Japan Prof. Sato came to visit B&K in Denmark and with their own

eyes see the level recorder and the company. Beranek's visit was the beginning of a lifelong friendship.

4.3 The pistonphone (around 1950)

After the war, there was difficulty with the long-term stability of measuring microphones and therefore a simple and easily transportable calibration method was needed. Best it would be if it produced sound in the same way as the sound sources to be measured, i.e. typically vibrating surfaces. It is significantly easier to make a stable sound source than a stable microphone with associated electronics. The pistonphone from approx. 1950, based on two pistons, is ideal for the purpose and provides a stable and portable calibration option for condenser microphones. Brüel emphasizes that the pistonphone is extremely stable – and mentions, for example, that after 43 years of use the accuracy still remained within $\pm 0,03$ dB [2]. By calibrating before and after measurements, you could compensate for minor changes in microphone sensitivity – which was a real risk at the time.

4.4 The condenser microphones (1950; 1955)

Already at the end of the 1930s, it had become clear that the Rochelle salt used at the time was bad for normal microphones, because the sensitivity varies with the moisture content. In the USA, they standardized e.g. a 1" condenser microphone developed at Bell Lab and produced by Western Electric (type no. WE 640AA), which was however smaller than 1". Unfortunately, the WE 640AA became more sensitive over the years (0.5-1.5 dB/year) – which was not optimal for a microphone designated as an American laboratory standard. In addition, it was a disadvantage that the WE 640AA had problems in free field, as the membrane was placed in a cavity/recess in the microphone housing under a ring and the front grill. From 1950, B&K sold condenser microphones, developed and produced by the Fono Film company who continued A. Poulsen and A. Petersen's⁵ activities for sound recording instruments. These microphones had a diameter of 36 mm, but both this and other condenser microphones also became more sensitive over the years. The phenomenon of the unstable sensitivity was quite inexplicable. Brüel recounts in [2]: "One evening in 1954, I sat and played with a piece of paper, which I held firmly to the surface of the table with strong pressure with my hand. When the hand that pressed the paper was still, the paper also remained completely firm, even if it was pulled hard. But if you moved your hand just a little, the paper could slip out. Here was the solution to the problem. If the microphone's ring and housing occasionally had dif-

ferent temperatures, even enough bolts could not prevent a minimal slippage between the ring and housing, with the result that the membrane could move a millionth of a millimeter. The result was that the microphone became more sensitive. If a microphone were to be more stable, it was therefore necessary that the diaphragm had a crystalline connection to the housing by either welding, hard soldering, or galvanic deposition". The detailed development of B&K's condenser microphones and pre-amplifiers was due to Gunnar Rasmussen's¹² great efforts as an extraordinary developer over a large number of years.

From 1957 B&K was on the market with 1" measurement microphones (type 4131-4132) with far fewer parts than existing microphones which resulted in superior mechanical stability, improved temperature coefficient and long-term acoustic stability.

Later B&K's condenser microphone type 4160 became the new WE640-equivalent and thereby *the* American laboratory standard microphone. According to [5] Gunnar Rasmussen tells that "Then I felt that we had helped put B&K on the world map, at least within acoustics". In 1958 the ½" microphone was launched, and this type is today the dominant type of measurement microphones, see Figure 7.

Brüel tells in [2]: "For 25 years, B&K condenser microphones had the privilege of being the world leader and earned then between Euro 4 and 6,5 million annually".

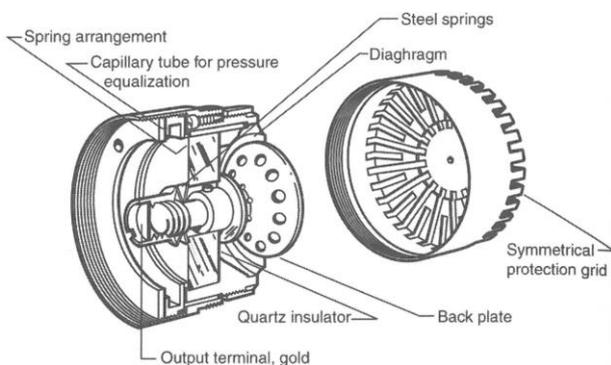


Figure 7. B&K's ½" measurement microphone [3]

4.5 The Artificial ear (1965)

Around 1965, there was disagreement about how an artificial ear should be designed. There was a need for a measurement system that ensured uniform and calibrated results for measurement of e.g. telephones and hearing aids. Together with Gunnar Rasmussen, Brüel had to develop a method to carry out some of the first measurements of the impedance of the ear canal as a function of frequency. They used two 3 mm condenser microphones that were inserted into the ear in parallel and in a form that completely closes off to the outside world except for a ventilation channel. One microphone act as a transmitter and emits a frequency-independent volume velocity. The second microphone measures the sound pressure, which is proportional to the impedance, because the volume flow is constant. With this basis, they could construct an artificial ear with an impedance corresponding to their measurements, see Figure 8.

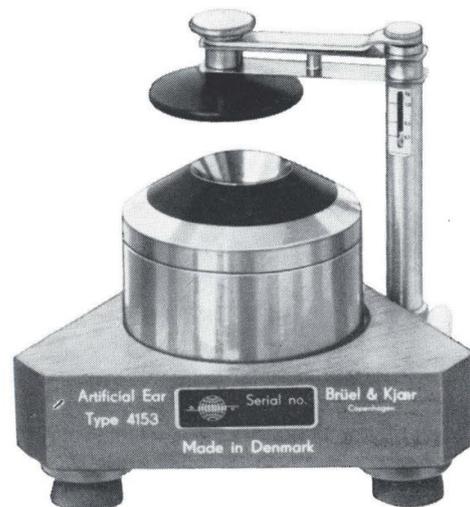


Figure 8. B&K's artificial ear [2]

In this way, "Brüel's and Gunnar Rasmussen's ears share the honor of being the basis for all current telephone measurements and measurements on mobile phones and hearing aids worldwide" [2]. Especially the Danish hearing aid industry has had a fascinating development, which is linked to the high level of knowledge in acoustics at the universities and in the industry, not least in the company B&K, which has attracted many skilled acousticians from all over the world.

¹² Gunnar Rasmussen (1925 -), 1950 BSc E., employed at B&K same year. 1994 founder of the company G.R.A.S. Sound & Vibration which i.a. manufactures microphones.

5. THE DANISH HEARING AID COMPANIES

Hearing aid has a long history in Denmark. The hearing aid company Oticon¹³ was established in 1904 selling imported American hearing aids based on Alexander Graham Bell's telephone principle [1], [6]. Due to WWII, it became very difficult to get the hearing aids from the USA and Oticon started its own production and in 1945 the first Danish hearing aid was ready. Another company Danavox¹⁴ produced their first hearing aid in 1947. In 1950, a law was passed on public hearing care with free hearing aids for the Danish population. This created a very large need for hearing aids but also for technical specifications and quality control. In 1953 IEC's WG 6 "Hearing Aids", whose chairman Fritz Ingerslev¹⁵ was a central person in Danish Acoustics, prepared IEC recommendation 118 "Measurements of Electroacoustic Characteristics of Hearing Aids". Hearing aids were subjected to input control using artificial ears, which B&K also produced in the late 1960's. The 3rd Danish hearing aid company, Widex¹⁶ was established in 1956. These three companies were in 1986 part of a joint research collaboration with the Danish Technical University, the ODIN-project⁵, with the purpose to investigate the possibilities of using digital signal processing in hearing aids. The results were extremely useful. Today all hearing aids are digital.

High technical quality and far-sighted commercial and scientific collaborations – supported by a strong university environment – have led to a thriving industry which has led to that every second hearing aid in the world is said to be "Danish".

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¹³ Approx. 19.000 employees (2022).

¹⁴ Now GN Hearing, part of the GN Group, approx. 7.500 employees (2023).

¹⁵ Fritz Ingerslev (1912-1994), 1936 MSc, 1953 Dr.Techn., 1946-1981 Head of the Acoustical Laboratory, 1954-1975/1975-1982 Prof. in low-current electronics/building acoustics, 1955 co-founder of DAS, 1968-1987 chairman of ISO TC43 "Acoustics" and its SC1 "Noise".

¹⁶ From 2019 Widex became a part of WS Audiology (W for Widex, S for Silvantos). Approx 12.000 employees (2022).



BUILDING ACOUSTICS AND THE “MILLION PROGRAMME” IN SWEDEN

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ABSTRACT

The paper focus on the development of building acoustics in Sweden exemplified by the activities at Chalmers University of Technology. Developments are often initiated by incidences where people meet at a place in a certain context. So also happened in Sweden in the middle of the forties when Per Bruel came as refugee from the German occupied Denmark to Chalmers where he started the Chalmers Acoustic Laboratory. He was soon joined by Uno Ingård who later was professor at MIT. At that time Sweden was in a transformation process from an agrarian to a highly industrialized nation leading to a large urbanization. Shortage of housing and the need to increase housing standard led to the so-called million programme with the goal to build one million flats. New building technologies (e.g., light concrete walls or the use of prefabricated elements) as well as the need/wish for cost efficiency led however to buildings of varying quality with new challenges with respect to building acoustics. As consequence building acoustics was identified as important part in the education of civil engineers and in 1962 Chalmers established a professorship in building acoustics. In 1969 Tor Kihlman became the first professor in building acoustics in Sweden.

Keywords: *building acoustics, history, Chalmers University of Technology, Applied Acoustics.*

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1. INTRODUCTION

To describe the “Activities in Acoustics of European Research Centers and Companies during the 20th Century” can be an overwhelming task, even in a smaller context such as Sweden. The task becomes even more challenging having in mind that such a paper only can be a reconstruction of history and therefore not necessarily the truth, but an interpretation by the authors. To make the task at all doable the authors limited themselves in three aspects. The broad field of acoustics is narrowed to building acoustics. Instead of focusing on Sweden as a whole, western Sweden and especially Göteborg has received the main attention. Finally, the time period has been limited to the first seventy years of the 20th century.

This does not mean, that there has been no development of other areas in acoustics in Sweden or that activities in building acoustics only took place in Göteborg, or there has been no development of building acoustics later in time.

We hope, however, that the narrowed focus in this paper allow for demonstrating how an area such as building acoustics is established in a socio-economic context. It is this context which formulates the needs for a discipline and can be seen as one of the driving forces for its development. This background is described in Section 2.

In addition, the development of a new discipline needs talented people full of scientific curiosity willing to enter terra incognita. Those people met just by chance at Chalmers in the forties and fifties of the 20th century as described in Section 3. The paper is concluded with some general remarks concerning the take aways when following history of a discipline from such a distance point of time (Section 4).

2. BACKGROUND – THE DRIVING FORCES

In Sweden cities like Göteborg started to grow in the 19th century. At the beginning of the 19th century Göteborg had 13000 inhabitants which was about doubled around 1850. In 1914, however, the number has been grown to over 180000. The ongoing industrialization and globalization with Göteborg as the main harbor of Sweden attracted people from the countryside to the city. Between 1900 and 1915 companies such as AGA, SKF, ESAB and VOLVO were founded with need for labour. Because of these new establishments, Göteborg started to grow outside its original borders. Industry but also the housing for people only found adequate space in the periphery of Göteborg.

1879 the first tram line, a horse-drawn tramway, was opened and successively extended. With its electrification around 1902, the extension of the tram system gained speed. New industry and living areas were placed in the vicinity of the tram stops. This, however, led exact as in many other cities, to a very sparse city structure, which then leads to increasing vehicle traffic. After the second world war the number of passenger cars increased rapidly from ca fifty thousand in Sweden to over two million 1970 and around five million today.

According to [1] the period between 1870 and 1970 comprises the most successful part of Swedish industrialization and growth. On a per capita basis, only the Japanese economy performed equally well as the Swedish in this period.

2.1 The Million programme

Rapid economic growth and urbanisation created a shortage of housing. In addition, the standard of many existing housings was low and not considered to be valuable enough to preserve. The need to build new flats was already a political issue before the second world war. In the late forties the building activities accelerated. Figure 1 shows the number of flats built in the period between 1950 and 2020. Although the expression “million programme” considers a political decision for the period between 1964 and 1974, even before this period a substantial number of flats were built.

To build one million new homes in a country with at that time less than eight million people was an ambitious public housing programme. In addition to the economical challenge the ambition was increased by aiming on building new subareas at high quality with a good range of services including schools, kindergarten, public spaces or libraries, and meeting places for different groups of households.

Most of the apartments followed a well described standard concerning size, use of space, furniture etc. A majority of the "standard three-room apartment" (two-bedroom apartment) type of 75 m², planned for a Swedish model family of two adults and two children.

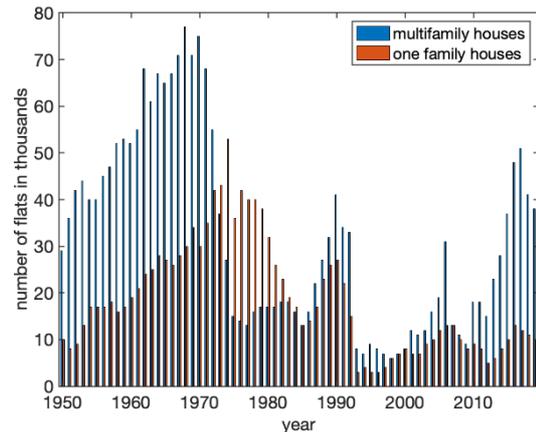


Figure 1. Number of flats built each year in multifamily houses and small one family houses in Sweden based on data from SCB (Statistics Sweden).

Not only the size was standardized but also the building materials and technologies used. Typically, prefabricated slabs were mounted in a very efficient way to multistory houses. Typical example of a building site although from the sixties is shown in Figure 2.



Figure 2. Building site 1961, typical multistory house with prefabricated elements [2].

2.2 The acoustic challenge

To be efficient from an economic perspective beside standardization, cheaper and lighter building materials were needed. The choice was light concrete slabs for building up single and double walls both as facade walls but also in between flats. This choice then turned out to create serious problems with respect to the acoustic properties of these buildings. The archive at Chalmers Applied Acoustics contains a substantial number of reports on air-borne and impact sound insulation measurements in these new buildings. Figure 3 is an illustration taken from one of these reports [3]. It exemplifies two of the main acoustic problems occurring. The negative consequences of the critical frequency around 800 Hz typical for 7 cm light concrete and leakages due to insufficient quality in the building process at high frequency.

The report was written by Tor Kihlman in 1959 at this time a 25 year old engineer who 10 years later became professor for building acoustics at Chalmers (see Section 3).

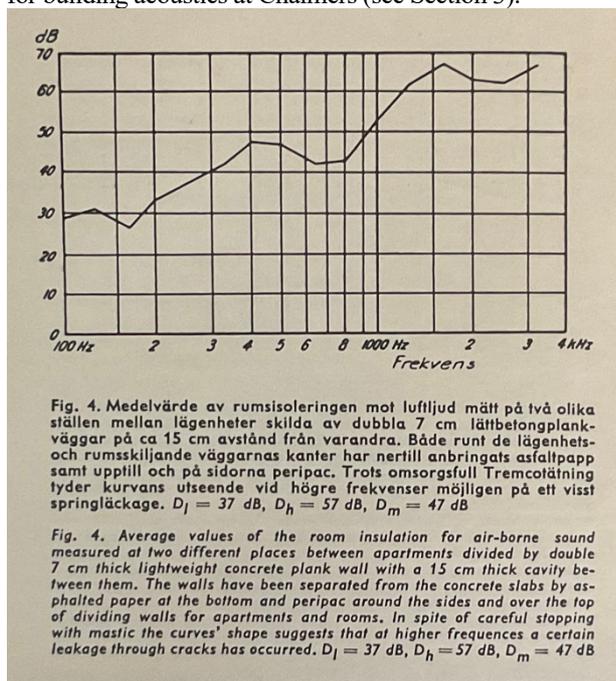


Figure 3. Measurement of air-borne sound insulation published in [3].

The problem with the critical frequency in the middle of the relevant frequency range would not surprise anyone today, but one should have in mind that Cremer's paper on the

theory on "sound insulation of thin walls with oblique sound incidence" [4] has been published as recently as 1942. In addition, although education in building acoustic existed in some places as courses or parts of courses, the education of acousticians as a profession was not taking place in Sweden.

The various problems with the acoustic performance of the buildings from the fifties and sixties of the 20th century led to an increased attention for building acoustics in society. Universities like Chalmers even considered the education in building acoustics as a chance to attract more students for the civil engineering programme. This was one reason to create a chair in building acoustic (see Section 3.2)

The building boom in that period in connection with an acoustically unfortunate solution also triggered need for research and, last but not least, work for acoustic consultancies.

3. BUILDING ACOUSTICS AT CHALMERS UNIVERSITY OF TECHNOLOGY

3.1 The early days at Chalmers

The very first time acoustic is mentioned to be part of an education at Chalmers was in a course in the architecture (byggnadskonst) in 1885. The teacher was Bror Viktor Adler, professor at Chalmers, and responsible for a number of iconic buildings in Göteborg. The part of the course was called "acoustic rules" [5].

The Chalmers acoustic laboratory was founded 1943/1944 under the lead of Per Bruel. 1942 he had started the company Brüel & Kjær together with Viggo Kjær. Short after he emigrated to Sweden. Denmark was occupied by Germany and Per Bruel did not find work in Denmark he liked to do as he said in an interview [6]. In Sweden he first worked for a company where he designed absorbers for their factory halls. Then he got the question to come to Chalmers to build up an acoustic laboratory. This included two measurement rooms in a shelter in a basement at Chalmers. Later a little anechoic chamber was added for the calibration of microphones. Much of his time was devoted to build instrumentation for acoustic measurements. During that time a prototype of the famous dynamic level recorder has been developed. The Chalmers Acoustic Laboratory under the lead of Per Bruel also carried out various building acoustic field measurements. All the reports from this time are still in the archive of Applied Acoustics at Chalmers. During the review of the reports two reports from 1946 was especially interesting. The first one describes measurement techniques used by the Chalmers Acoustic Laboratory for sound pressure, reverberation time, absorption, airborne and

impact sound insulation. As an example, Figure 4 documents the equipment for measuring reverberation time. In the introduction of the report, it is stated that the report was written for the Swedish Building Research Department as input for standardization of the measurement methods. It also is stated that the presented methods and equipment differ from what has been used in Sweden at this time and that the methods rather follow such developed for instance in the USA or Germany. Obviously, it was the intention of the Chalmers Acoustic Laboratory to lift measurement techniques in acoustics in Sweden to state of the art level as it was in other countries at that time. Maybe not too surprising having in mind that the lab has been started by Per Bruel.

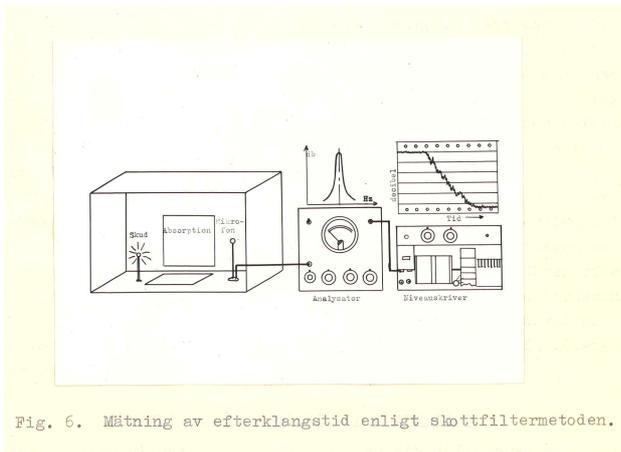


Figure 3. Measurement of reverberation time in [9].

The second report which attracted our attention describes what could have been the very investigation of peoples' opinion about the sound insulation in their houses in Sweden. It is based on a questionnaire which was sent to different households. At the very end Per Bruel however concluded that the number of households investigated might have been too little and he refers to a similar study carried out in London. Per Bruel stayed at Chalmers until 1948 at least part time. When Per Bruel started the lab, he got a young assistant, Uno Ingård (in his early twenties) who after the war took over as director of the lab. During this time Uno Ingård worked on his licentiate degree which he finalized in 1948 [8] under supervision of Olof Rydbeck (professor, electronic engineering) and supported by Hjalmar Granholm, professor for building technology

(where the Chalmers Acoustic Laboratory was localized). With his increasing interest in acoustics but also with his enthusiasm for Phillip Morse, Uno Ingård decided to go to the MIT to get a PhD in acoustics, which he also managed. Before he left, he persuaded Stig Ingemansson, a friend of him, to take over the position as director of the Chalmers Acoustic Laboratory. After his PhD supervised by Richard Bolt, who was director of the MIT Acoustics Laboratory, Uno Ingård returned for a two-year period to Sweden to teach acoustics at Chalmers. At that time acoustics had already been part of the education for civil engineers. Uno Ingård probably wrote the very first course material for a course on building acoustics at Chalmers before he left for the MIT. In 1952 Uno Ingård decided to go back to the MIT where he later became professor of physics and of aeronautics and astronautics while the Chalmers Acoustic Laboratory continued its work under Stig Ingemansson.

3.2 The Chalmers Acoustic laboratory becoming Applied Acoustics

The laboratory has since its start in 1943 been a rather independent part of building technology at Chalmers. Activities in the fifties and sixties mainly concerned building acoustic measurements due to the expansive phase of the building boom with new building methods and building materials. The poor acoustic performance of some of the new buildings were frequently subject of reports and discussions in the daily press. This might have been a major reason that in 1963 Chalmers decided to create a professor position in building acoustics. However, the position was then announced much broader including not only architectural acoustics but other areas of applied acoustics. The open position was announced 1964, but it took until 1969 when Tor Kihlman was appointed as professor by his majesty king Gustaf VI Adolf of Sweden. In the evaluation committee for the position were beside others Per Bruel and Fritz Ingerslev, at that time already professor for acoustics at the Technical University of Denmark. The delay in filling the position at Chalmers might be explained with the difficulties to find a person with the proper educational profile. During the period between 1963 and 1968 Stig Ingemansson was acting as professor and teaching at Chalmers. However, although Stig Ingemansson was a very good acoustician and teacher, he did not have a PhD. When Tor Kihlman finalised his PhD in 1968, he was the very first PhD in building acoustics and probably in acoustics in general in Sweden.

Stig Ingemansson continued with his consultancy company (Ingemanssons Ingenjörbyrå) which he had started in 1956 as a sideline. The company grew quickly to become the

largest acoustic consultancy in sound and vibration in Sweden and probably in the whole northern Europe.

With a chair in acoustics the Chalmers Acoustic Laboratory became Applied Acoustics as an independent unit. In 1969 Applied Acoustics moved to its own newly built facilities designed by Tor Kihlman. It included besides others an anechoic chamber, a transmission suite, and a reverberation chamber. Although this is not really correct, we often call the year 1969 the official start of Applied Acoustics.

4. FINAL REMARKS

The million programme was not only a housing programme but had the clear intention to increase the standard of living. The standardized building methods developed during the million programme made it possible to build a high number of flats in a short time. However, this also resulted in that the acoustic problems associated with the building techniques occurred in many buildings. What was intended to increase the standard of living obtained a bad reputation.

Sometime this bad reputation was not always deserved as not all buildings produced during this time period were built using e.g. light-weight concrete, but with building technologies having high acoustic standards. It is often believed that the acoustic problems were caused by too low requirements in the building legislation at that time. This is however not true; the sound insulation requirements from 1946 in Sweden are essentially equivalent to the current legislation (the main difference is that today's legislation includes frequency bands down to 50 Hz). This means that a building that was built in the fifties and that fulfil the sound insulation requirements in the 1946 legislation would also pass today's airborne sound insulation requirements. The bad reputation of the million programme buildings is thus mainly connected to the chosen construction, not to the legislation.

However, as a consequence of the bad reputation, building acoustics became an important issue in Sweden in the fifties and sixties. It coincides with a time in Europe where building acoustics made substantial progress in knowledge and also where talented people with scientific curiosity engaged themselves in the development of building acoustics as a subdiscipline in acoustics.

The start of the acoustics laboratory at Chalmers might look as being based only on a series of lucky incidents. However, on the second glance it is obvious that this would not have happened without people - not necessarily acousticians - who recognized the needs of building acoustics in society and who took the chances offered by history. They asked Per Bruel to come to Chalmers and to

build up the acoustic lab when he was in Sweden. They persuaded a talented student named Uno Ingård to get engaged in acoustics although he at the beginning felt that acoustics was not what he wanted to work with. Ingård also found with his friend Stig Ingemansson the perfect person to take over the acoustic laboratory. Finally, the Civil Engineering Department at Chalmers University of Technology at that time understood the value in having a chair in acoustics. That they found with Tor Kihlman an adequate candidate was not self-evident, having in mind that until that time, in Sweden there had been no one been awarded with a doctoral degree in building acoustics.

The activities at Chalmers University of Technology (and at other academic institutions), together with the emerging awareness of acoustics being an important issue for the "normal" person, triggered a high activity of product development during the sixties. Several manufacturers of building materials started their own engineering divisions, and some of them even built their own acoustic laboratories. The curiosity and inventive skills of the engineers working at these labs drove product development, both from a scientific and from an economic point of view. The aspiration to find efficient and simple solutions to the acoustic problems was admirable. There is a waste number of reports with acoustic measurements that were published during this time period, measurement data that still is valid today. One could argue that this implicitly means a lack of technical development after that period, but the authors of this paper would rather say that the early researchers have done their tasks very well.

Over the years, the insight for the need of education and research in acoustics varied among those who make decisions in politics or at universities. However, the need in society stayed strong and one has to conclude that the challenges to create acoustic environments which support health and well-being rather increased than decreased.

Finally, the authors would like to thank Tor Kihlman, who taught us the importance to fight on all levels for a better acoustic environment in our daily life. This includes not only the education of young students as future noise and vibration specialists, the research with relevance for society, but also influencing politics for the peoples' best. Without Tor Kihlman, the acoustics at Chalmers but also in Sweden would have never developed to what it is today.

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Development of acoustic measurement instruments by Norsonic - a historical overview

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ABSTRACT

The paper describes the start of the Norwegian manufacturer of acoustic instrumentation in 1967, Norsonic AS, and some of the company's first instruments for acoustic measurements.

Keywords: History, acoustic measurements, Norway.

1. INTRODUCTION

Norsonic has since its foundation in 1967 supplied acoustic instrumentation in Norway and worldwide. In addition to the development, manufacturing, and marketing of acoustic instrumentation the company also operates the only accredited calibration laboratory in Norway for acoustical quantities. The position of Norsonic's accredited laboratory status is put in context with the acoustics laboratory at NTH/NTNU in Trondheim which previously upheld a similar status. This historical overview is partly based on a previously published overview of Norsonic's history [1], [2]. The first author has been with the company since 1971 and has thus participated in most of the development over the years.

2. THE START

The company was founded in 1967 as Nortronic AS, but the start goes back to 1965 when the Norwegian Commission

for aircraft noise requested an instrument for the measurement of "Perceived Noise Level" or PNdB, a unit developed to show the perceived annoyance from jet airliners. The audio physicist at Oslo University Hospital, Gordon Flottorp, was the chairman for this commission. An ISO recommendation described the calculation procedure based on octave-band analysis. The request was put to Central institute for industrial research (CIIR). The institute, owned by the Council of Norwegian Science and Research (NTNF) was founded after the Second World War in order to build up the post-war country. The institute is today a part of SINTEF. The institute developed an instrument based on analogue, and partly nonlinear computations to replace the time-consuming, manual calculation of the PNdB level. The value was presented directly on a meter in real time and a voltage output allowed the levels to be recorded by a y/t recorder. The leader of the department at the institute doing the instrument development was Asbjørn Nordby, who was later appointed the first CEO of Norsonic and Håkon Bjor, brother of the first author, was one significant member of the development staff.

After a successful development, the CIIR tried to find companies for the manufacture and marketing of the developed analyser, since it was assumed that there was a market for such instruments also other places than at Fornebu, at that time the main airport for Oslo. No response was obtained from the industry, and after some time parts of the development team headed by Asbjørn Nordby decided to start a new company for the purpose. In opposition to how research institutes today in general encourage the development of new companies, CIIR was sceptic but accepted to transfer the knowledge since no other had showed interest. The company, named Nortronic AS, was founded 1. March 1967 as a joint-stock company with a stock-capital of NOK 10.000, the first year without any employees.

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One main marketing activity was a full-page announcement in “Flying Review” leading to a request to demonstrate the PNdB calculator for British Aircraft Corporation (BAC) developing the supersonic transport aircraft Concorde. Asbjørn Nordby and Håkon Bjor went to Bristol for the demonstration on a low fair travel budget. They received an order for NOK 70.000 the same evening and rumours tells that they immediately changed to a better hotel that had just been opened by the queen of England.

3. THE “SAMPLING FILTER”

Although BAC was very satisfied and ordered one additional unit the next year, the market did not develop as hoped. This was mainly due to two factors: a simpler frequency weighting method (D-weighting) was developed for general monitoring of aircraft noise, and for aircraft certification, the octave-band analysis was replaced by one-third-octave analysis. The company therefore looked for alternative products. A patent devolved by Håkon Bjor (still at CIIR) to control the frequency of active filters over a broad frequency range, was developed for use in different products. It was a central part of several instruments in the following years, such as tracking oscillators and filters. The method was named “sampling filters” although the important issue was that the effective value of resistors in an “RC-circuit” was controlled by the on/off ratio (duty-cycle) of a high-frequency switch in series with each resistor in the RC-network. In this way, the frequency of a filter or an oscillator could be varied up to four decades with high accuracy.

4. INSTRUMENT TYPE 811 – THE DOOR-OPENER

The first international accepted instrument, next to the PNdB-instrument, was the instrument type 811 for building acoustic measurements, such as airborne and impact sound insulation in buildings including the measurement of reverberation time. This single instrument replaced several heavy instruments normally used for such measurements. It was especially important to replace the level recorder which alone had a weight of more than 20 kg. A postulate from the acoustic consultant Gunnar Nesheim was in general accepted: All acousticians have a painful back!

Instrument type 811 included a band limited noise generator, a 1/3- or 1/1 octave band filter, a digital true RMS level detector developed during the M.Sc. thesis of the author, and an analogue reverberation time calculator. The frequency range was from 50 Hz to 10 kHz. This instrument was very well accepted in the European market

and was really a door-opener to the German market when it was demonstrated at the Electronica exhibition in München in 1972. This instrument later received a gold medal at an exhibition in Leipzig in 1974. The instrument was developed after discussing the performance requested by early acousticians, such as Gordon Flottorp, Asbjørn Krokstad, Tor Erik Vigran and Wilhelm Løchstøer. One of the challenges with analogue instrumentation was to square a signal with the large dynamic range normally found in acoustics. If the amplitude varies in a range 1:1000, the square has a range 1:1000 000. In the instrument, this was solved with a digitally controlled amplifier to normalize the signal before squaring. The needed amplificant then indicated the RMS-value of the signal. The value of the level and the reverberation time were presented on a digital display – quite modern at that time. Still the instrument needed to have an analogue display with a pointer since the standard for sound level meters only specified analogue meters with a specified minimum size!

However, after the well-received introduction, it was requested by a new German standard to step the octave filter in half-octave steps. This was not foreseen by the construction and looked like a real obstacle for further sales. Due to the application of the “sampling filter”, the problem was solved one late evening by a switch and a resistor which shifted all frequencies by one half octave. The instrument was in production from 1972 to 1982.



Figure 1. Asbjørn Nordby demonstrating instrument 811 after receiving gold medal for the instrument in Leipzig (1974)

5. REVERBERATION DECAY SHOWN GRAPHICALLY

The next important instrument was type 823 introduced in 1980, a replacement for type 811. This was also a serial analyser mainly for building acoustic applications. The instrument was controlled by a microprocessor and the “sampling filters” were replaced by digitally controlled analogue filters, and most important: the results were presented on an integrated video monitor which allowed the reverberation decay to be displayed graphically. The instrument had two measurement channels so the level in the source and the receiving room could be measured simultaneously. Most parts of the instrument, except the graphical screen, were developed through a special delivery of a four-channel instrument to NTNU/Acoustic Laboratory in Trondheim in 1976. The application of the programmable 4-bit and 8-bit microprocessors had started some year earlier in a control unit for type 811 and additional instruments like a microphone multiplexer. The development of programs for the microprocessor was demanding at that time, the code was stored as rows of up to eight holes punched on a paper tape. It was very time-consuming to make even small changes in the low-level code. The instrument was manufactured in the years 1981 to 1990.



Figure 2. The first portable computer of the Acoustic laboratory NTNU, for control of the 4-channel custom-built analyser made by Norsonic. Vigran and Sørsdal (NTNU/Sintef) are seen in the background, Krystad from Norsonic operates the computer.

6. REAL TIME ANALYSER AND SOUND INTENSITY

The analysers 811 and 823 could only measure one frequency band at the time. The first instrument measuring all frequency bands simultaneously was RTA830. Such analysers are normally called “real-time analysers.” The instrument had two measurement channels. In addition, the instrument was intended for the measurement of sound intensity where one channel was used for the sound pressure and one for the particle velocity. The company received official research funding from the Council of Norwegian Science and Research (NTNF) for the development of the analyser and the accompanying microphone system for sound intensity named 216.

The development started around 1980 and the first instrument was delivered in 1984. At that time, no digital signal processor was available, and the instrument was therefore based on the use of ordinary logical components. Digital signal processing normally makes use of additions and multiplications. Without a signal processor, multiplications were very demanding and a table look-up involved a large, two-dimensional table. The solution was to use a logarithmic number system with an additional sign-bit. Due to the number system, multiplications were replaced by simple additions. However, the linear addition of the logarithmic values was difficult. The problem was solved like how an acoustician adds levels in dB: Take the largest value and correct for the difference between the numbers. The correction could be made with a small, one-dimensional table. The application of the logarithmic number system was very efficient and led to a very compact instrument and low power consumption compared to other real-time analysers at that time.

Sound intensity may be calculated from the observation of sound pressure and sound particle velocity. The pressure was measured with an ordinary pressure microphone but the particle velocity was measured by two pairs of ultrasonic transducers. The transducer system, named 216, was one of few transducers measuring the particle velocity directly. The first unit was introduced in 1985.

The speed of blowing air adds to the speed of sound traveling in the same direction. The particle velocity may be considered as an alternating airflow. By having two pairs of ultrasonic transducers sending the ultrasound in two opposite directions, an airflow will reduce the transmission time for one set and increase the transmission time in the other. This was the principle for measurement of sound particle velocity in the intensity probe 216, where the difference in transmission time was measured as a phase difference between the sets of ultrasound transducers. The

challenge by the measurement principle was that the particle velocity in a sound wave is very, very low compared to the normal speed of sound. The distance between the source and receiver for the ultrasound was 30 mm limiting the upper frequency range to 6,3 kHz.

Although the probe hardly was an economic success, it was technically interesting, and made a good job for promoting the dual channel analyser. The probe 216 was manufactured in the period 1985 to 1992.



Figure 3. The sound intensity probe 216.

FFT-analysis was also introduced as an option in the RTA 830 instrument. In cooperation with Volkswagen AG, the real time analyser was adapted to the measurement of noise from vehicles in a system called VNA 836. Photo-detectors and a radar logged the position and speed of the car.

7. MLS AND HADAMARD

The successor of 830 was named 840 and introduced in 1992, again a dual channel real time analyser with a frequency resolution down to 1/12-octave and this time with a colour screen to display the results. At this time digital signal processors were available, and the logarithmic number system, successfully applied in 830 analyser, has never since been used by the company. The introduction of the processors solved a lot of problems from the time of analogue instrumentation like squaring of a signal with a wide dynamic range.

With TRA 840, the MLS-technique was introduced. A maximum-length-sequence (MLS) is a signal appearing in the number theory. The technique allowed the impulse response of a transmission system to be obtained by processing the response of the noise-like MLS-signal by a very efficient algorithm: Fast Hadamard transformation. The technique, although then not yet allowed by international standards, improved the measurement accuracy of reverberation time and airborne sound

insulation. Even situations where the measurement signal was buried in noise could be measured.

8. REQUEST FOR SMALLER INSTRUMENTS

In addition to the more sophisticated instruments, there were demands for smaller, hand-held sound level meters. The first, Nor110, launched in 1988, was not really small, but battery operated and powerful and could do frequency analysis.

A further development was the dual channel instrument Nor121 launched in 1998. The instrument was the first of our instruments with the ability to not only measure, but also to record the microphone signal digitally. The user could then after the measurement listen to the noise event. The instrument was used for general noise measurement, for reporting the annoyance from noise, and for building acoustic measurements. The instrument was the first instrument from Norsonic to apply the swept-sine method. This technique has mainly the same applications and features as the MLS-technique, but is more robust to distortion in the transmission channel and to fluctuation due to temperature and wind. Experience from the development was used to create a new ISO standard 18233: "Acoustics - Application of new measurement methods in building acoustics" (2006) which describes both MLS and swept-sine methods. This instrument was later developed to be an instrument for measuring noise during periodic test of cars (EU-control), Nor117. It had the ability to measure the rotational speed of the engine by analysing the sound from the car.

The next small instrument, Nor116, was a step back to microprocessor controlled analogue circuitry. It measured simultaneously A-weighted equivalent SPL and C-weighted peak SPL and was therefore a typical sound level meter. The company had then expanded the range from low-volume sophisticated instruments to a higher volume market. The analogue signal processing in the instrument applied the logarithmic ratio between the voltage and current in a semiconductor diode for squaring the signal to obtain the RMS-value.

The successor of 116 was an instrument with the same small size, but applying digital signal processing, Nor 118. This allowed real time frequency analysis in 1/1-octave and third-octave bands to be included together with additional functions such as the measurement of reverberation time. Except from being a one-channel instrument, the functionality of the real time analysers Nor830 and Nor840, was achieved in a small hand-held, battery-operated instrument. The technology was developed and brought to

the next generation, Nor140, that was still a very successful instrument.



Figure 4. Example of later developments of instrumentation from Norsonic. A conventional outdoor microphone is supplied with the “Noise compass” (lower part) indicating the direction to the dominant sound source. The three-dimensional direction is obtained from 8 microphones in the lower part. AI may be used for identification of the type of noise.

9. RELYING ON THE CONDENSER MICROPHONE

During the history of Norsonic, the transducer for sound has mainly been the ½ inch condenser measuring microphone. It is impressive that this transducer has survived this long time-span without significant changes. The production method has improved and electrets have partly replaced the externally supplied polarization voltage, but the specifications have not changed significantly. However, the electronic system measuring and analysing the output voltage from the microphone has had an enormous development as indicated above. Today, for most applications, an analogue to digital converter measures the signal from the microphone directly and all signal analysis is done by digital circuitry.

10. NORSONIC CALIBRATION LABORATORY

Norsonic started to manufacture sound calibrators in 1995. This also raised the question on how to secure the quality of

the calibration. The work for establishing traceability to internationally recognised references, led to the creation of Norsonic Calibration Laboratory. The laboratory was accredited by Norwegian accreditation first time in February 1999. Since Norwegian Accreditation is one of the signatories to the EA Multilateral Agreement for mutual recognition of calibration certificates (European Cooperation for Accreditation), calibrations done by the laboratory have a worldwide acceptance. The laboratory is still the only accredited calibration laboratory for acoustical quantities in Norway. The position of Norsonic’s accredited laboratory status is put in context with the acoustics laboratory at NTH/NTNU in Trondheim which previously upheld a similar status. The service is open for equipment from different manufacturers.

11. INTERNATIONAL STANDARDIZATION

It has always been important for Norsonic to design instruments fulfilling current international standards. The history back to the PNdB-calculator showed how important it is to be prepared for changes in the standards for instruments and measurement methods. Since the first part of 1980 the company has participated in the development of National and International standards through ISO and IEC.

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INTERNATIONAL NETWORKS OF FINNISH ACOUSTICIAN PAAVO ARNI

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ABSTRACT

Mr Paavo Arni (1905–1969) was a central influencer in the field of acoustics in Finland since the 1940's until his death. Paavo Arni ran an engineering office specialized in acoustics, but he was also active in education, founding of the Acoustical Society of Finland, preparing regulation concerning sound insulation of apartment buildings as well as occupational noise. He also supported research on acoustics in Finland and internationally, too. In addition, he was the author of the first Finnish handbook on acoustics published in 1949. The base of the wide range of activities of Paavo Arni was possible because of his main work at the Finnish Broadcasting Company YLE. He began as a studio manager in 1931 and ended his career as a technical director of YLE. Construction of studios provoked a need for knowledge on acoustics. Paavo Arni started to form international connections with other broadcasting companies and with acousticians in the 1930s by making visits, attending conferences and hosting international experts' visits in Finland.

Keywords: *acoustics, history of technology, technology transfer, Finland*

1. INTRODUCTION

Paavo Arni (1905–1969) graduated in 1930 as a Master of Science in Technology from the Department of Mechanical Engineering of the Helsinki University of Technology, but he only worked for a short time in the mechanical engineering industry. During the Great Depression, Arni

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could not find work in his own field, and he ended up working for the Finnish Broadcasting Company as a studio technician in 1931. [1–2]

The engineers of the Finnish Broadcasting Company had to familiarise themselves with acoustics when designing the studios [3]. Arni described this phase in 1963 [4]: “In Finland, as elsewhere, broadcasting was on the rise in the 1930s. Broadcasting technology, like the closely-related sound film and record technology, urgently needed information on sound production, room acoustics, sound insulation and problems encountered while listening to the programme. For this reason, broadcasters in different countries, including Finland, began to delve deeper into sound engineering issues and their solutions.” Knowledge of acoustics was thus focused in the Finnish Broadcasting Company, where an acoustics laboratory was built in the basement of the Radio House (1934) to measure the acoustic properties of structures and materials. [1, 3, 5, 6] Paavo Arni has been featured in research literature from the point of view of the Finnish Broadcasting Company, in which he held several significant positions [1, 3 7–9]. For example, in 1952, he was responsible for the radio broadcasting of the Helsinki Olympic Games around the world (Fig. 1) and, at the end of the decade, for the launch of the Finnish Broadcasting Company's television operations [9–10]. During his career at the company, he progressed to become Chief Engineer in 1952 and then Technical Director in 1964 [9].

Arni's work as an acoustics expert, on the other hand, is only briefly mentioned in research literature [1, 9]. His activities have been described a little more extensively in one area of acoustics: in research on the technology transfer that led to the creation of sound insulation regulations for residential buildings. Paavo Arni played a key role in the technology transfer that took place in the absence of domestic research [11].

Paavo Arni's work as an acoustics expert took place in an era when the advancement of industrialisation and

urbanisation in Finland made noise caused by machines, traffic and housing a social problem that had to be solved in some way. In order to achieve this, it was necessary to define what amount of noise was acceptable in different situations and from different sound sources, meaning that regulations on noise had to be created [11–12]. At the same time, there was also a need for acoustic expertise because theatres and orchestras that had previously performed at town halls, clubhouses, community centres, workers' halls or community halls began to be municipalised, and performance facilities were built for them [13–14]. In the 1940s, people also started paying attention to the acoustics of schools [15].

The purpose of this article is to present Paavo Arni's work as an acoustics expert through his international connections. This article examines how Arni networked with international acoustics experts and how he acquired information about acoustics and conveyed it to Finland. The article focuses on Arni's activities especially in the fields of building and room acoustics and noise abatement. Electroacoustics is excluded from this article. Similarly, Arni's activities at the Finnish Broadcasting Company are not discussed except in relation to building and room acoustics.



Figure 1. Paavo Arni interviewed by the reporter Saara Palmgren during the Helsinki Olympic Games in 1952. Source: Finnish Broadcasting Company Yle Archives.

2. FORMATION OF ARNI'S INTERNATIONAL CONTACTS

The construction of the Finnish Broadcasting Company's studios required knowledge of acoustics, but there was no research and teaching in acoustics in Finland in the 1930s [16]. Therefore, knowledge had to be acquired from elsewhere through technology transfer. One form of this is study trips abroad, which Paavo Arni frequently had in various positions at the Finnish Broadcasting Company from the 1930s onwards [3]. For example, in 1938, he acquainted himself with "modern studio constructions" in Sweden and, in the following year, he studied the sound insulation solutions of the recently completed Vienna radio building [17–18]. Some of Arni's trips were to acoustics conferences [19–20], but most had to do with broadcasting technology. In connection with his travels, he seems to have tried to arrange visits to research institutes specialised in acoustics or to building sites of acoustic interest. Arni's travels abroad were reported in newspapers in great detail. His interest in acoustics is shown by the fact that the newspapers quoted his often enthusiastic reports of the sound insulation, room acoustics and noise abatement solutions he had seen on the way.

An example of how technology developed abroad was transferred to Finland is adjustable room acoustics. In 1946, on the initiative of Hella Wuolijoki, Director General of the Finnish Broadcasting Company, a new music hall was planned for the company in an old military building, the Riding Hall of the Guard in Helsinki [7]. In *Helsingin Sanomat*, the leading Finnish newspaper, in autumn 1946, Arni said that he had recently made a "quick expedition to similar buildings abroad" and continued: "I travelled to Copenhagen and Brussels." In the recently completed radio buildings of these cities, his attention was first drawn to the fact that the concerts broadcast were not played in studios but in concert halls located in the radio buildings. In Brussels, he was also interested in the fact that the studio could "automatically change the acoustics", i.e. use electric motors to rotate hexagonal columns covered with different sound-absorbing materials to the positions required to achieve the ideal reverberation time for the performance [21]. However, the Finnish Broadcasting Company's project to convert the old Riding Hall into a 600-seat concert hall was soon dropped [22].

Despite the discontinuation of the concert hall project, plans for a music studio continued and, in 1949, the Finnish Broadcasting Company's "hall with changing acoustics" was introduced to the press, mentioning that it was unique in the Nordic countries. The hall featured structures that could be turned by hand to adjust the reverberation time to

suit different purposes. Arni (Fig. 2), who presented the hall in *Helsingin Sanomat*, predicted that “construction plans for larger halls in the next few years will use the ‘invention’ now being tested by the Finnish Broadcasting Company.” [23] This did happen: in the early 1950s, the new buildings of the School of Business and Hanko City Hall were completed, and Arni had designed adjustable acoustics for both of them. A little later, the new building of the Swedish School of Economics was completed, featuring a 350-seat festival hall with mechanically adjustable acoustics [24–25].



Figure 2. Paavo Arni presents the adjustable acoustics of the music studio of the Radio House of the Finnish Broadcasting Company in 1950. Source: Finnish Broadcasting Company Yle Archives.

After developing the Finnish application of adjustable acoustics, Arni did not keep it to himself; in 1950, he published its principle in a Finnish architectural journal in his article on the acoustics of the new building of the School of Business [24]. In the same year, he published an article on the subject in *The Journal of the Acoustical Society of America* [26]. In spring 1950, Arni gave a presentation on “changing acoustics” at an international acousticians’ meeting in Marseille. As a result, a group of English acousticians visited Finland in the summer of that year to learn more about this technique [27].

The above shows how Arni networked with foreign acousticians. Thanks to the networking, in the 1940s and

1950s, the meetings of the Acoustical Society of Finland featured presentations by three Danes – Dr. Per Brüel, founder of an acoustic measuring equipment company and assistant professor at Chalmers University of Technology, Dr. V. L. Jordan, leading room acoustics expert in the Nordic countries, and Professor Fritz Ingerslev – as well as Swiss Professor Willi Furrer [28]. During a trip to the United States to study acoustic laboratories in spring 1948, Arni met Leo Beranek, the American regarded as the most important acoustician of the 20th century. During the trip, he visited the acoustic laboratory at MIT, where Beranek was working at the time [29]. At the International Congress of Acousticians in London in summer 1948, Arni met Beranek again [19]. Late that same summer, Beranek made a visit to Finland, hosted by Arni, and mentioned it in his memoirs published 60 years later [30].

By the beginning of the 1950s, Paavo Arni had achieved international fame to the extent that, in autumn 1951, he was invited to London to listen to the problematic acoustics of the newly completed Royal Festival Hall at a test concert [31]. The building was one of the first large concert halls built after the Second World War, and its design had aimed to follow up-to-date guidelines on acoustics as closely as possible [32]. Of the 18 members of the international group of experts that evaluated the acoustics of the originally 3,404-seat concert hall, Arni was among the most critical [31]. The international appreciation for Arni is also shown by the fact that Professor Willi Furrer, after visiting Finland in 1953, published a spectacularly illustrated article on Arni’s design work in the *Schweizerische Bauzeitung* [25].

3. ORGANISATIONAL DUTIES AND PUBLICATIONS

A visit to Helsinki in 1942 by the German Dr. Hans Joachim von Braunmühl proved to be very important for the development of acoustics in Finland. The visit was related to the Finnish Broadcasting Company’s project to construct a new radio building to replace the quickly overcrowded premises on Fabianinkatu [9]. An expert in acoustics and broadcasting technology, von Braunmühl gave a presentation for the company on the acoustic design of buildings, sound insulation, room acoustics and the acoustic properties of building materials. The presentation was published as an extensive two-part article in a Finnish professional journal, translated by Arni [33–34].

The radio building project was dropped during the war, but von Braunmühl’s presentation generated so much interest and enthusiasm for acoustics that, on 25 August 1942, a

meeting was held at the Finnish Broadcasting Company, attended by 11 experts from various fields of acoustics, from both business life and research institutions. Paavo Arni had prepared a proposal for the meeting that “a society should be established in Finland whose task would be to carry out research and measurements in the field of acoustics and to carry out educational work among certain circles.” All participants supported the establishment of the society and, at the end of the meeting, an ad hoc committee was set up to draw up rules for the society. Paavo Arni was elected secretary and convener of the committee. [28]

After the committee had completed its duties, the founding meeting of the Acoustical Society of Finland was held on 29 March 1943, during which the rules of the society were approved. According to them, the society was to organise meetings, presentations and lectures, promote research in the field and the distribution of professional literature, engage in publishing and advisory activities and develop Finnish vocabulary in the field. Paavo Arni was elected a member of the Board of the society. He served as a member of the society’s Board for three periods totalling 26 years, 15 of them as Chairman. [28]

The Acoustical Society of Finland became one of the channels for technology transfer. Although technology transfer relies to a large extent on the actions of individual people, the connections between them and their mobility, contact between individuals is not enough to make it happen. In order to adopt the technology, a more general interest is needed, and the activities must be well-organised [35]. The Acoustical Society of Finland provided the necessary framework for the promotion of acoustics. During its first ten years of operation, eight foreign experts lectured at its meetings. Arni himself gave nine presentations during the same period, at least four of which were based on his trips abroad. [28]

Arni’s most important literary work is a textbook published in 1949, *Käytännöllisen akustiikan perusteet (The Basics of Practical Acoustics)* [36], which remained the only Finnish textbook in the field for over a decade. It was also the result of Arni’s trips and contacts abroad and visits by international experts to Finland: of the 61 titles in the book’s bibliography and recommended literature, 20 were from Germany, 13 from the Nordic countries, 10 from the United States, and the rest from the United Kingdom, the Netherlands and Switzerland. There were only six Finnish references [11]. Based on his book, Arni also lectured on an acoustics course at the Helsinki University of Technology in the 1950s [16]. The development of teaching was on the agenda of the Acoustical Society of Finland during the time that Arni was on its Board [28].

In the 1950s, Paavo Arni’s organisational duties expanded outside Finland. He attended the first International Congress on Acoustics (ICA) in Delft in 1953 [37]. Towards the end of the congress, the representatives of the four Nordic countries gathered together and decided to establish a Nordic acoustical society under the name *Nordiska Akustiska Sällskapet (NAS)* [38]. The Acoustical Society of Finland appointed Paavo Arni as Finland’s representative to the Board of the Nordic society [39]. After the success of the NAS test conference held in Copenhagen in 1954, the first actual Nordic conference was held in Helsinki in 1956, as the Acoustical Society of Finland was the oldest national society in the field in the Nordic countries [38]. The conference was opened by the Chairman of the hosting society, Paavo Arni. When the ICA congress was held in Copenhagen in 1962, the NAS was responsible for organising it. The advisory committee of the congress was composed of members of the Boards of the national member societies. Finland was represented by Paavo Arni and two other Finns [40].

4. COMMITTEE AND RESEARCH WORK

At the initiative of the Acoustical Society of Finland, the Government appointed a committee at the beginning of 1945 to prepare legislation to reduce the harmful effects of noise at workplaces. Paavo Arni was invited to be a member of the committee but, after the death of the Chairman of the committee, he was appointed as the new Chairman in 1947 [19]. At this time, Arni’s study trips abroad were to sites that were important in terms of hearing protection. For example, during a trip to Sweden for a presentation at a radio association meeting in Stockholm in 1945, he studied the “magnificent work done at the ASEA factory in Västerås to suppress the high levels of noise in the factory and offices” [41]. Between 1948 and 1949, he made three trips abroad in connection with the work of the noise abatement committee: in April 1948 to the United States to study acoustic laboratories and “the protection of workers against noise” [28], in July 1948 to the International Congress of Acousticians in London, and again to London in September–October 1949. The experts that Arni met during his travels provided the Committee with research literature in the field [19].

Later, Arni was involved in an international committee relating to noise. Since the early 1950s, he had been involved in motor vehicle noise measurements and, when the NAS started developing a measurement standard in 1956, Arni was appointed as the leader of the standard

workgroup. The workgroup's proposal later served as the basis for the international ISO standard [38].

In 1947, the Board of the Acoustical Society of Finland decided to approach the Ministry of the Interior with a letter on "the drafting of sound engineering standards for house builders". This had been influenced by the fact that, at the society's meeting in the spring of the same year, Dr. V. L. Jordan from Denmark had given a presentation on the regulations concerning sound insulation and noise abatement in various countries. The secretary of the society, Paavo Arni, submitted Jordan's presentation to the press, translated into Finnish, with the title *Current legal rules and standards concerning noise and sound insulation in different countries*. A proposal for a committee for the drafting of domestic standards was submitted to the Ministry of the Interior in spring 1948. [11]

Achieving sound insulation standards proved to be a long-lasting project, whose important milestones were the sound insulation research committee in 1952–1955 and a committee established in 1957, which drafted a proposal for sound insulation regulations published in 1960. Paavo Arni was invited to be a member of both committees. The achievement of sound insulation regulations is probably societally the most significant project initiated by the Acoustical Society of Finland, resulting in the improvement of sound insulation in homes and thereby affecting the daily lives of millions of Finns. The project was not completed until 1975, when the National Building Code of Finland was published for the first time. Its part C1 dealt with sound insulation in buildings. [11]

Arni did not only use his networks to transfer information from abroad to Finland, but he was also able to support research elsewhere [31]. For example, he was involved in organising Leo Beranek's second visit to Finland in 1960, when Beranek was writing the first version of his famous book on concert halls [30]. During his trip, Beranek visited the University of Helsinki's festival hall, which had been rebuilt and expanded in 1945, as well as the Helsinki House of Culture and the Turku Concert Hall. Arni was responsible for acoustics in all these projects. At the time, the Turku Concert Hall (Fig. 3) appears to have had a good international reputation, and thus it and the House of Culture were introduced in Beranek's book [42].

In the early 1950s, the diffusion of the sound field in a space was a subject of interest to researchers, since it had been observed that the smooth surfaces favored by the architecture of the era did not provide listeners with the same experience of acoustics as old concert halls did, even if the reverberation time was the same. Arni defined the matter as follows: "In old halls, the sound is reflected from broken surfaces, columns, recesses, balconies, etc. as

irregularly as possible, diffusively, which again means as even a reflected sound field as possible throughout the hall, i.e. balanced and good audibility. In a modern hall, special diffusers are used in an attempt to achieve this diffusion [...]". Convex spherical surfaces had been arranged on the surfaces of the festival hall of the Swedish School of Economics designed by Arni and finished in 1953, and vertical wavy and prismatic surfaces had been placed on the side and back walls [43]. Arni's article in the architectural journal in 1955 is apparently the first Finnish text describing diffusion.

Among the researchers Arni met in London in 1951 [31], Professor Willi Furrer and Professor Erwin Meyer from the University of Göttingen studied diffusion in the early 1950s. Furrer also gave a presentation on the subject at a conference in Delft in 1953 [44], attended by Arni. In an article in 1955, Arni said that a research group at the University of Göttingen was studying diffusion in acoustically interesting halls [43]. The festival hall of the Swedish School of Economics was also measured in this context, and so was the Turku Concert Hall. Paavo Arni was involved in arranging access to both spaces for the group of researchers, for which Meyer and Thiele thanked him in a scientific article they published in 1956 [45].



Figure 3. Paavo Arni was responsible for the acoustics of the Turku Concert Hall finished in 1952. Source: Sibelius Museum archive.

5. ARNI AS ACOUSTICAL DESIGNER

Paavo Arni's design work includes concert halls and theatres, sacral buildings, educational institutions, office buildings and hotels. They were designed by leading Finnish architects of their time, and Arni seems to have had long-term cooperation especially Kaija and Heikki Siren. Of Alvar Aalto's projects, Arni was involved in designing

the acoustics of the House of Culture, and he also started design work for the Finlandia Hall before his death. Abroad, Arni participated in the design of the Brucknerhaus Concert Hall in Linz and the studios built by Austrian Radio in Salzburg, Innsbruck, Dornbirn and Linz [46]. Paavo Arni described his design work methods in his book *Käytännöllisen akustiikan perusteet (The Basics of Practical Acoustics)* [36]. According to Architect Alpo Halme, who worked in Arni's office, the book "contained almost all the relevant information that existed at the time." [46] In terms of measurement methods, Arni refers in his book to the German DIN 4110 standard from 1938, and he presents a mass law formula for the calculation of airborne sound insulation. For room acoustics design, the book presents formulas by Sabine, Eyring and Millington for calculating reverberation time. In addition, there are tables and diagrams on both topics with recommendations for different spaces and material properties. Arni also introduces the use of geometric room acoustics in design and the light and water models used by the Finnish Broadcasting Company. Geometric room acoustics were used by him in the design of the rebuilding of the University of Helsinki's festival hall.

The water model was used in the discontinued project of converting the Riding Hall of the Guard into a concert hall for the Finnish Broadcasting Company. Arni explained the water model to the press in 1946: "A metal basin has been made that closely follows the shape of a concert hall, and its bottom is made of glass. There is also a metal ball hanging at the end of a kind of lever. The metal ball corresponds to a sound source in tests made with this water model. When it touches the surface of the water, waves are formed on the surface that correspond to sound waves. By observing these, we can see how sound waves are reflected from the surfaces of the room." It was also reported that the Finnish Broadcasting Company's personnel had named the water model "Arni's aquarium" (Fig. 4). [47]

When Arni started his work, there were yet no international standards for acoustic measurements, but he lived to see measurement standards published for most conventional measurements. The magnitude of the change is illustrated in an article published by Arni in 1944, in which he describes reverberation time measurements in concert halls. At the time when Arni wrote his article, an orchestra was used as the sound source, and works suitable for measurements included "for example, the end of Sibelius's 5th symphony, the first bars of Beethoven's Coriolan Overture, the beginning of Bach's Toccata and Fugue in D Minor." In all of these works, forte sections are followed by rest, during which the reverberation time could be measured from the decrease in sound pressure. [48]



Figure 4. Paavo Arni demonstrates his aquarium, a water model built to study the acoustics of the upcoming concert hall in 1946. The hall was never realized. Source: Finnish Broadcasting Company Yle Archives.

6. CONCLUSIONS

The above is an account of Paavo Arni's work as an acoustician and his international networks, created on the basis of written sources. In recent decades, the history of technology has been dominated by ideas about the social construction of technology [49], with little attention being paid to the influence of individuals on the development of technology. According to the sources available, Paavo Arni seems to have been an exceptionally influential person in his field. Arni's design work does not necessarily differ in significance, scope or difficulty from the work of other Finnish acousticians who worked at the same time. What sets him apart from his contemporaries is his broad scope and apparent desire to acquire and share information as well as to promote the development of the field of acoustics and the creation of better sound conditions in Finland. This also made him the first internationally known Finnish acoustician who, through his extensive contacts, was able to convey the latest research information to Finland, where the chair of acoustics was established only after his death [16]. Paavo Arni's main occupation in the fast-developing broadcasting industry provided opportunities to establish

contacts with international acoustics experts at conferences and on study trips and by hosting visits by foreign experts in Finland. Young Arni's aim seems to have been to learn about different fields of acoustics and convey information about them to Finland. Subsequently, he seems to have sought to alleviate the social problems associated with sound conditions that were developing, as exemplified by his work in the noise abatement and sound insulation committees. His work thus ranged from practical design work to societal influence. Some of the things he advocated became reality only after his death, such as the issuing of sound insulation regulations [11].

A key part of Paavo Arni's career and achievements was the international network of experts that he had formed since the 1930s, which enabled the transfer of technology to Finland, where there was not much teaching and research of acoustics in the absence of a chair. Juhani Borenus, who worked under Arni at both the Finnish Broadcasting Company and Arni's engineering office, assumed that Arni's mobility in international circles was made easy by his diverse language skills and his childhood environment in the multicultural Vyborg. Although Arni managed to achieve a lot and was efficient in all his duties, his work was left unfinished: Paavo Arni died in spring 1969 at the age of 64, and his plan to focus on acoustic design during retirement did not materialize [1].

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HISTORY OF THE INSTITUTE OF ACOUSTICS AND SPEECH COMMUNICATIONS OF THE TU DRESDEN

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ABSTRACT

At the TU (formerly TH) Dresden, acoustics is part of the faculty of electrical engineering. Its development started in 1911 when HEINRICH BARKHAUSEN was appointed Professor for “low-current technology”, which was an umbrella for both, acoustics and communications engineering. BARKHAUSEN contributed to the field of acoustics, e. g., with the first device for loudness measurement. After the war and the retirement of BARKHAUSEN, several new institutes were established from which we mention: (1) the Institute of Electrical and Building Acoustics led by WALTER REICHARDT, contributing to many fields of technical acoustics, and (2) the Institute of Telecommunications Engineering supervised by KURT FREITAG, contributing to speech acoustics with the design of a vocoder and the measurement of speech quality. When the GDR performed a “higher education reform” in 1969, the acoustical activities were concentrated in a department for “communications and data acquisition” which included five chairs in acoustics, sensors, speech, and measurement. This step took into account the growing role of computer technology. After the political changes in 1990, the number of chairs was reduced to two which is expressed by the today’s name “Institute of Acoustics and Speech Communications”. The paper is finished by an overview on the recent activities of the institute.

Keywords: History of Acoustics, History of Speech Technology, TU Dresden

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1. EARLY DEVELOPMENT UNTIL WW II

1.1 The Beginning of Activities in Acoustics

The *Technische Bildungsanstalt* (Technical School) Dresden, the germ cell of today’s *Technische Universität* (TU), was founded in 1828. The founding director was WILHELM G. LOHRMANN (1796–1840). He cooperated in his own scientific work with FRIEDRICH W. OPELT (1794–1868) who was also interested in musical acoustics and published a book on the tone system in 1852. He invented a special version of the hole siren for his experiments [1].

It took some years before the new school reached an academic level in education. In 1842, AUGUST SEEBECK (1805–1849) was appointed director of the school and professor for physics and natural science. He was an important physicist with special interest in acoustics [2]. After his death the field of acoustics became deserted.

After the turn of the century, there were two activities in the field of room acoustics. The school had been upgraded to a *Technische Hochschule* (TH) meanwhile. RICHARD HEGER (1846–1919) was a teacher at the famous Holy Cross High School and also honorary professor at the TH Dresden. He had research activities in room acoustics since 1890 and read lectures on this topic since 1910. He was given the opportunity to establish a laboratory for experiments in room acoustics at the TH in 1912 which he used until his death [3, pp. 18 – 19].

The other early representative of the field of room acoustics with a special focus on church acoustics was JOHANNES BIEHLE (1870–1941). He was already a renowned director of church music in Bautzen when he additionally started his work in physics at the TH Dresden in 1908. He worked at the Physical Institute where he had his own laboratory, but in 1916, he changed to the TH Berlin where he was the founding director of the Institute of Room Acoustics, Church Music, Organs and Bells [4].



Figure 1. Bust of HEINRICH BARKHAUSEN, installed at his 100th birthday in the Barkhausen building of the TU Dresden. Artist: WALTER HOWARD (1910 – 2005). Photograph by ROLF DIETZEL.

1.2 The Era of Heinrich Barkhausen

A continuous development of acoustics at TH Dresden started with the appointment of HEINRICH BARKHAUSEN (1881–1956, Fig. 1) as professor for “low current engineering” (which we would call telecommunications today) in 1911. He came from Berlin where the big electric companies like Siemens & Halske had installed laboratories for research and development in telephony and (later) radio technology. They required new knowledge on speech production, hearing, and speech transmission. This is the reason why electroacoustics developed under the umbrella of telecommunications in that times.

BARKHAUSEN considered this development in his scientific work very early. In his dissertation (Göttingen 1906) on the generation of vibrations, he had already treated electrical, mechanical and acoustic vibrations from a uniform point of view. He elaborated the electromechanical analogies so far that the symbolic method of AC networks could be transferred to mechanic and acoustic systems. The symbolic method (commonly known as “ $j\omega$ calculation”) was invented by KARL STEINMETZ (1856 – 1923) in 1889.

BARKHAUSEN is mainly known for his contribution to theory and application of the electronic valve and his work as academic teacher [5]. The acoustic community values him for his numerous contributions in this field. They started with underwater acoustics while



Figure 2. Loudness meter from BARKHAUSEN, produced by *Siemens & Halske* starting 1927. Photograph of the device in the HAPS collection of TU Dresden [39, no. 15–1].

BARKHAUSEN was conscripted during WW I [6, 7]. His studies on the sensation of loudness [8] resulted in the first commercially available apparatus for loudness measurement (Fig. 2). To honor him, the “bark” unit for the critical bands remembers his name.

After several attempts, BARKHAUSEN succeeded with the expansion of the capacity by an extraordinary professorship for telecommunication systems and technical acoustics in 1938. It was given to WALTER WOLMAN (1901–2003) who also came from *Siemens & Halske*. Unfortunately, the following WW II and the switch to military research prevented the intended consolidation of the acoustics branch. Along with nearly the whole town, the TH Dresden was completely war destroyed in February 1945, and the work was suspended.

1.3 The Institute of Scientific Photography

The sound film played an important role in the application of electroacoustics since its invention in the 1920s. Dresden had a long tradition in the photographic industry, and therefore the TH Dresden included an important Institute of Scientific Photography. In the time when HELLMUT FRIESER (1901–1988) was the director, the institute conducted research on the sound film, including the development of a sound spectrograph based on an optic-photographic method [9].



Figure 3. WALTER REICHARDT in a lecture. Private photograph, approx. 1968.

2. NEW INSTITUTES AFTER WW II (1950–1968)

The difficult restart after WW II included a re-organisation of the faculties. After some intermediate steps, the TH Dresden opened a separate Faculty of Electrical Engineering in 1952. It was subdivided in a “high current” and a “low current” branch. The latter, which represented the BARKHAUSEN tradition, included finally six institutes [10]. Two of them were important for the further development of acoustics and will be treated here. The TH Dresden was upgraded to a university (TU) in 1961.

2.1 Institute of Electrical and Building Acoustics

The successor of BARKHAUSEN in the field of technical acoustics was WALTER REICHARDT (1903–1985, Fig. 3) [7, 11]. He finished his Dr.-Ing. thesis at BARKHAUSEN in 1930 and worked as senior engineer in various German broadcasting companies. After WW II, the TH Dresden tried to win REICHARDT as a university lecturer which finally resulted in his appointment as professor and director of the new *Institute of Electrical and Building Acoustics* in 1950.

REICHARDT developed the institute into an important facility in research and teaching; it was the leading institute in acoustics in the German Democratic Republic

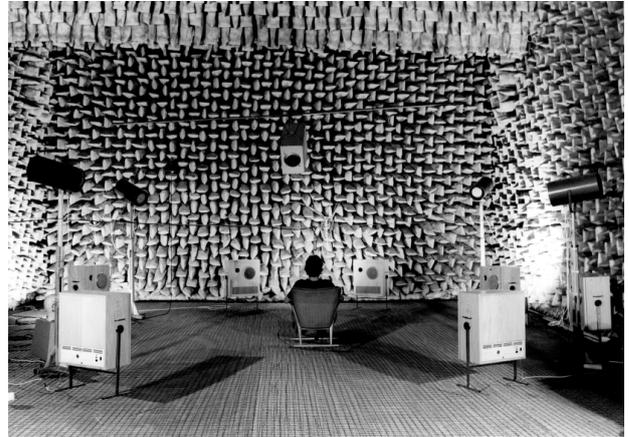


Figure 4. Synthetic sound field in the big anechoic chamber. Photograph from 1978 by ROLF DIETZEL.

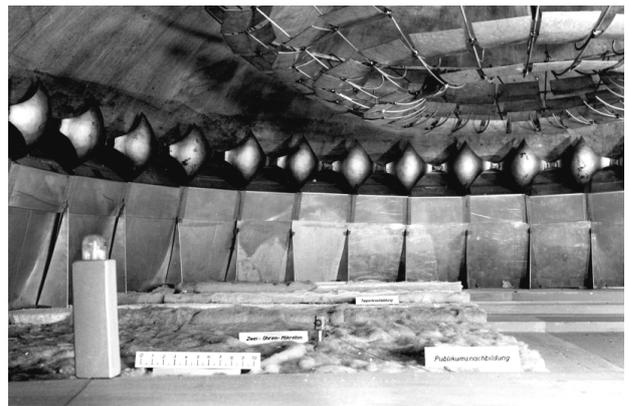


Figure 5. Model of the congress hall of the “House of Teachers”, constructed for acoustical planning at TU Dresden. Original building erected at the Alexanderplatz in Berlin 1961–1964. Photograph by ROLF DIETZEL.

lic (GDR). Until his retirement, 419 Dipl.-Ing., 41 Dr.-Ing., and 3 habilitation degrees were acquired at the institute [7]. The institute was installed in a new building, today known as the Barkhausen building, and was equipped with a reverberation room as well as two anechoic rooms (Fig. 4).

REICHARDT made an important contribution to theory and application of the electromechanical analogies. He published a textbook [13] on electroacoustics which gained the status of a standard work.



Figure 6. KURT FREITAG (left), director of the Institute of Telecommunications, and WALTER TSCHESCHNER. Private photograph from the 1960s.



Figure 7. W. TSCHESCHNER in front of the Dresden vocoder in 1962. Newspaper photograph [19], reproduced from [20].

In the first years, speech analysis was one of the research topics of the institute [12]. Soon, this field was moved to the Institute of Telecommunications Engineering (see 2.2).

REICHARDT and his institute became famous for the development of acoustic model measurement technology and its application to numerous cultural buildings (Fig. 5), including the acoustic design of the rebuilt Semper opera house in Dresden.

The development of an adequate terminology and a correct usage of physical units was another focus of REICHARDT. He was a very active member of German and international boards for standardization.

Before REICHARDT retired in 1968, two of his scholars were appointed professors: WOLFGANG KRAAK (1923–2015) for Technical Acoustics in 1966 and ARNO LENK (1930–2017) for Electromechanical Measurement Technology in 1967. Considering the modified profile, the institute was renamed *Institute of Technical Acoustics* in 1967. The title of the REICHARDT's renowned textbook was changed accordingly [14].

2.2 Institute of Telecommunications Engineering

The *Institute of Telecommunications Engineering* of TH Dresden was founded as one of the last new institutes in 1954. It was directed by the physicist KURT FREITAG (1901–1977, Fig. 6). He had an excellent background in research and industrial development in the field of wire-bound communications technology [15]. The tasks of the institute included speech transmission and speech quality

measurement.

In the post-war times, the vocoder raised strong interest. There was an obvious question whether this innovation was really able to transfer speech economically with reasonable quality. The best way to find an answer was the investigation of a prototype, which was designed in the framework of the Dr.-Ing. thesis of EBERHARD KROCKER (1927–2022) in the years 1954–1957.

This was the starting point for speech technology research at TH/TU Dresden. When KROCKER finished his thesis, the field of work was transferred to WALTER TSCHESCHNER (1927–2004, Fig. 7), thus initializing his scientific carrier as a pioneer of electronic speech signal processing. As a first task, he investigated the objective evaluation of speech comprehensibility, which resulted in an analysis of the German sounds, summarized in his Dr.-Ing. thesis from 1961 [17].

The continuation of this research was mainly thanks to the linguist GEORG F. MEIER (1919–1992), director of the Institute of Phonetics and Communications Sciences of the Humboldt University Berlin since 1961. He organized a network in speech communications research in the GDR which included the activities of TSCHESCHNER. Therefore it was possible to install a project “physics of speech” which resulted in his habilitation in 1967. It shifted the focus from speech analysis to speech synthesis, which was still serving as an experimental method to clarify the acoustic structure of speech sounds. The production of synthetic speech for communication purposes was at that time at most a question for the future [18].

3. LABORATORY FOR COMMUNICATIONS AND DATA ACQUISITION (1968–1990)

3.1 The Higher Education Reform of 1968/69

The so-called 3rd higher education reform of the GDR in 1968/69 was intended to respond to new demands of the 1960s in society, science, and technology. The reform is seen controversially today, because it increased the influence of the state and party organs at the universities. But the engineering faculties benefited from the new structures, because they reflected the challenges of the upcoming electronic age. The Faculty of Electrical Engineering was re-organized in scientific units called “Wissenschaftsbereiche”, which we translate here as laboratories.

In this way, the *Laboratory for Communications and Data Acquisition* was installed at TU Dresden. It integrated the Institute of Technical Acoustics and parts of two other institutes with the aim to address the future requirements, which were expected to occur at the interfaces of the computer with its environments as well as with the human user. This decision was a very early one, compared to other German universities, and we count it as the founding act of the recent institute. The laboratory included four working groups, which are described very briefly in the following [10, 11, 21]. The name was changed to *Laboratory for Acoustics and Measuring Technology* in 1977. A specialist colloquium was organized by the laboratory every fourth year (Fig. 8).

3.2 Working Group on Technical Acoustics

The field of technical acoustics was considered so important that two professorships were established. The aforementioned W. KRAAK was in effect the successor of W. REICHARDT. Additionally, WALTER WÖHLE (1928–2020) was appointed professor for Technical Acoustics in 1970.

From the numerous activities of W. KRAAK, hearing acoustics, measurement of noise and its impact on human beings should be mentioned. The latter is known as “Dresden hearing damage model” [22]. He was one of the editors of a highly valued handbook on acoustics [23].

W. WÖHLE worked among other on sound propagation in buildings and applied and improved the method of statistical energy analysis.

W. KRAAK introduced the first lectures on digital signal analysis at the faculty. He retired in 1988. His successor was DETLEF HAMANN for the short time of only three years.



Figure 8. Representatives of the Dresden acoustics at the 8th “Fachkolloquium Informationstechnik” in January 1975. Left (2nd row) A. LENK; first row W. REICHARDT, W. WÖHLE, and W. KRAAK (standing). Photograph by ROLF DIETZEL.

3.3 Working Group on Electromechanical Measurement Technology

A. LENK continued in his new group the work on electromechanical systems and transducers. He developed the corresponding theory to a high level and summarized it in a textbook of three volumes [24]. One of the most important applications was the development of piezoresistive transducers for medical and other purposes.

3.4 Working Group on Speech Communications

W. TSCHESCHNER started as a lecturer in the new laboratory and was appointed professor for Speech Communications in 1972. Until his retirement in 1992, he supervised 37 Dr.-Ing. and Habilitation theses in the field of speech synthesis and recognition. The scientific results were applied in numerous projects of the *Kombinat Robotron* as well as the *Kombinat Musikinstrumente*. He developed new teaching activities in speech communications.

3.5 Working Group on Electronic Measurement Technology

The field of theory and application of electronic measurement was represented by UWE FRÜHAUF as lecturer since 1969, professor for Electronic Measurement Technology since 1975 [25]. The group was transferred to another institute in 1992.

4. INSTITUTE OF ACOUSTICS AND SPEECH COMMUNICATIONS

4.1 Reorganization in the Political Turn of 1990

In the framework of the political changes of 1989/90, the “laboratories” were re-organized to institutes. The Laboratory of Acoustics and Measuring Technology regained the historical name *Institute of Technical Acoustics*. The number of chairs was reduced to three in the following years, namely Technical Acoustics (WÖHLE), Electromechanical Systems (LENK), and Speech Communications (TSCHESCHNER). The annual German Acoustics Conference (DAGA) was organized for the first time in Dresden in 1994 to demonstrate the integration after the German re-unification.

When A. LENK retired in 1996, no successor was appointed. His working field was continued by his collaborator GÜNTHER PFEIFER who held the status of an adjunct professor since 1992 [26].

This means that two chairs with their corresponding working groups remained in the end. Their development will be explained subsequently. Details can be found in the annual reports from 1991 to 2013. Considering the designations of the two remaining groups, the name of the institute was changed in *Institute of Acoustics and Speech Communications* in 1999.

4.2 Working Group on Acoustics

When W. WÖHLE retired in 1993, the successor at the chair of Technical Acoustics was PETER KÖLTZSCH. He came from the *TU Bergakademie Freiberg* where he acted as professor for Fluid Mechanics. He supervised numerous research projects in the traditional fields of the institute, but also in new areas like sound generation, structure-borne noise, and flow acoustics [27]. Following an own design, the institute received an aeroacoustic wind tunnel with extremely quiet jet flow in 1996.

The name of the chair was changed to Communications Acoustics when it was posted for succession. It was passed to UTE JEKOSCH in 2005. She came from the *Rensselaer Polytechnic Institute*, Troy, N. Y., and was especially known for her work in sound design and sound quality [28]. She initiated the construction of a laboratory for multimodal measurement. In 2008 she brought the DAGA conference to Dresden for the second time. Additionally, the capacity of the institute was extended by the appointment of WOLFGANG KLIPPEL as honorary professor for electroacoustics in 2007.

The chair of Communications Acoustics was deputized by ERCAN ALTINSOY, a specialist in auditory-tactile interaction, since 2009. He was appointed professor for Acoustics and Haptics in 2016. His research group is investigating the relationship between physics (sound/vibration) and perception (auditory/haptic) [30] [31]. Furthermore the interaction of these two modalities is a topic of interest. The investigations are conducted in the fields of e.g. vehicle acoustics, household appliance acoustics, audio reproduction systems, psychoacoustics, vibroacoustics and VR. The aim is to create models which can predict (product-) perception of the acoustic and haptic properties [32]. He is one of the core team members of the cluster of excellence CeTI (Centre for Tactile Internet with Human-in-the-Loop) at TU Dresden (www.ceti.one/).

4.3 Working Group on Speech Communications

When TSCHESCHNER was retired in 1992, he was succeeded by RÜDIGER HOFFMANN who was already present as lecturer in Human-Machine Communications since 1986. He guided the Dresden sub-project of the German Verbomobil, which offered a tremendous chance under the new political conditions in the 1990s. He supervised 36 Dr.-Ing. and habilitation theses as well as numerous cooperation projects. He expanded the educational activities of the chair to the theory of signals and systems [29]. This resulted in the re-naming of the chair to System Theory and Speech Technology in 2007 and in the expansion of the scientific focus to cognitive systems.

PETER BIRKHOLZ started as Junior Professor for Cognitive Systems with tenure track as successor of HOFFMANN in 2014 and was appointed full professor for Speech Technology and Cognitive Systems in 2020. His group researches at the confluence of speech technology, phonetics, and machine learning. It follows a major interdisciplinary course and encompasses speech technology, instrumental and acoustic phonetics and medical technology. The research group develops and maintains one of the most advanced systems for articulatory speech synthesis [33] [34] (www.vocaltractlab.de) and techniques to recognize silently produced speech [35] [36] [37]. One of the silent speech techniques has led to the spin-off of *Altavo GmbH* in Dresden, which aims to give laryngectomies a new voice.

Two international conferences in speech communications were hosted in Dresden: the 3rd Int. Conf. on Speech Prosody in 2006 and the Interspeech in 2015.

5. THE HISTORIC ACOUSTIC-PHONETIC COLLECTION (HAPS)

The historic acoustic-phonetic collection (HAPS) has its roots in the rather long history of acoustics and speech communications at TU Dresden. A variety of old devices from half a century of research and development formed the base of the collection. It could be considerably expanded by devices from two old and renowned phonetics institutes in Berlin and Hamburg, thus extending the time span far into the pre-electronic era.

The HAPS is supervised by the author since his retirement in 2014. The objects are made available in two catalogue volumes [38] [39]. The collection is a place for historic research in communications sciences and media technology, which is summarized in a recent paper [40].

6. ACKNOWLEDGMENT

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ACOUSTICS IN GÖTTINGEN: RESEARCH AT THE DRITTES PHYSIKALISCHES INSTITUT DURING THE 20TH CENTURY (AND BEYOND)

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ABSTRACT

After its foundation in 1947, the Third Institute of Physics (Drittes Physikalisches Institut) at the University of Göttingen soon became one of the main centers of acoustics research in Germany, and also in Europe and possibly the world. This advancement was strongly connected with the personalities of Erwin Meyer, the founding director, and his successors, Manfred R. Schroeder and Werner Lauterborn. But also the variety, broad interest and interaction of all research groups at the Institute contributed to a special, cooperative and very fruitful atmosphere at the “Drittes”. Here, we very briefly review some scientific topics and important achievements at the Institute until the turn of the millennium, referring to general and physical acoustics, room and concert hall acoustics, underwater sound, and ultrasound and cavitation. The latter subjects are described in more detail to highlight the very early, but partly not well-known, fundamental and seminal works that had been conducted in Göttingen, already paving the way to important applications and actual research until today.

Keywords: *acoustics research history, room acoustics, ultrasound, cavitation bubble dynamics, sonoluminescence*

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1. INTRODUCTION

The “Drittes Physikalisches Institut” (DPI) was founded in 1947 at the University of Göttingen by uniting the “Institut für Angewandte Elektrizität” (Applied Electricity) and the “Institut für Angewandte Mathematik und Mechanik” (Applied Mathematics and Mechanics). Both had been established in 1889, following an initiative of the famous mathematician Felix Klein, to install applied research in Göttingen on a sound base. While the very roots of the “Drittes” lie in the applied sciences, the future should as well bring essential fundamental insights — primarily in acoustics, but also in optics, microwaves, and nonlinear dynamics. The variety of the Institute’s research spectrum was well described in German by the former adjunct “Schwingungsphysik”, which might be best translated to English by “oscillation and wave physics”.



Figure 1. The Institute building at Bürgerstraße 42 in Göttingen around the year 2000.

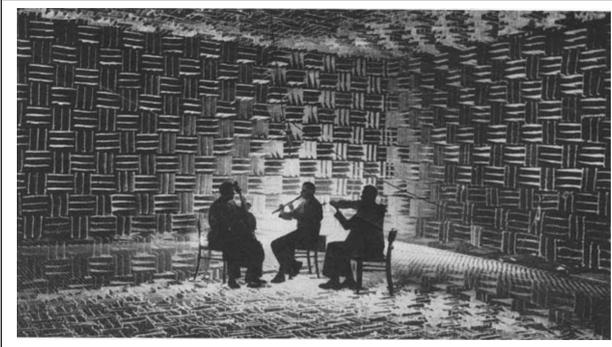


Figure 2. Anechoic room at DPI: inner dimensions of $5.5 \times 10 \times 14 \text{ m}^3$, and anechoic for acoustic waves above 70 Hz and for electromagnetic waves.

Most of the topics under study at the Institute were already pursued under Erwin Meyer, the founding director. He had a strong standing in applied and technical acoustics, electroacoustics, underwater sound, building acoustics, room and concert hall acoustics, but also started early research in ultrasound and cavitation. His successor as director in 1969, Manfred R. Schroeder, pursued room acoustics and added a focus on hearing and speech acoustics, coding and digital signal processing. This came along with applications of mathematics like number theory and fractals, and with the employment of computers. Werner Lauterborn became the third director in 1994. He further reinforced the use of scientific computing and established coherent optics and nonlinear dynamics in the Institute's profile. He was and still is very active in acoustic and optic cavitation, and this line of research led to pioneering works in laser science, high-speed photography and high-speed holography, as well as in chaotic systems. All directors were open to quite a variation of topics, and the Institute's research till and around the millennium is not sufficiently described without the contributions of many other groups and names being active in acoustics and further fields. Notably, room acoustics, acoustic cavitation and sonoluminescence (Kuttruff), ultrasound and microwave spectroscopy (Pottel, Kaatze), acoustics in rarefied gases (Sessler), aeroacoustics (Mechel, Ronneberger), underwater sound, absorbers and active noise control (Wille, Guicking), hearing research and psychoacoustics (Strube, Kollmeier, Kohlrausch) and nonlinear systems (Kurz, Partitz, Holzfuß, Mettin) have been pursued deeply. Further areas of study comprised low temperature physics, hypersound and phonon research, as well as organic semicon-

ductors (Helberg, Eisenmenger).

In the following we will sketch some important works and results of the broad spectrum of acoustics research at the Drittes. Due to the format of this article, this can be done only very briefly and by no means in completeness. For more details, we refer the reader to other sources, where the scientific history and activities at DPI have been portrayed quite elaborately. Namely, we recommend Dieter Guicking's book on Erwin Meyer [1], the Festschrift to the Institute's 60th anniversary [2], the Memorial Volume in Honor of Manfred R. Schroeder [3] and the book chapter "Erwin Meyer – Akustik in Göttingen" by Peter Költzsch [4].

2. GENERAL, PHYSICAL AND TECHNICAL ACOUSTICS

Erwin Meyer's interest and research was very broad, and thus nearly all aspects of acoustics were touched by his work. A consequent expression of this was his suggestion and co-foundation of the "European" acoustics journal *Acustica* in 1951. He served as the German editor the rest of his life, and this journal became a main channel of dissemination of the scientific results from the Institute until the 1990s, and partly till today.¹ Many earlier articles had been written in German, which was quite customary at that times, but this possibly hindered a wider spread and international recognition of several seminal works. Later, Meyer condensed his deep general and practical knowledge together with Ernst-Georg Neumann into the textbook *Physikalische und technische Akustik* (or just the "Meyer-Neumann") [5] that should become a long-term standard in Germany (and via translation to English as well abroad). Another standard was set by the textbook *Schwingungslehre*, written by Meyer and Dieter Guicking [6]. It was also by these (and other) books how the DPI coined the German acoustics community.

To have access to modern research facilities, the institute building near the city center of Göttingen (Fig. 1) was soon extended. The first installation was an emblematic anechoic chamber of quite large dimensions, suitable for sound as well as electromagnetic radiation, see Fig. 2 [7]. Its walls and also the floor (below a metallic net to walk upon) were equipped with large wedges of porous material (glass-wool) as absorbers, a common technique nowadays. The wedges had been made ab-

¹ Later, the journal was merged to become *Acta Acustica united with Acustica* and now continues as *Acta Acustica*.

sorbant to electromagnetic waves by graphite powder. The room served for a variety of measurements, ranging from sound source characterization to hearing research and psychological acoustics.

Another unique facility was added a few years later: a reverberation room, again suitable for acoustic and electromagnetic waves due to a copper foil on the walls, floor and ceiling [8]. Figure 3 shows the interior of the room that had inclined corners, equipped with additional reflectors to generate a diffuse sound field, suitable for instance for absorbance measurements of materials.

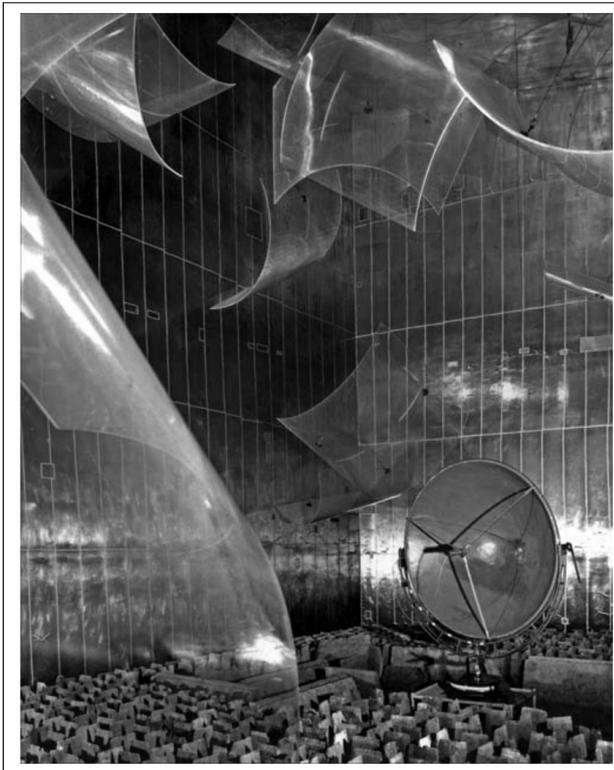


Figure 3. Reverberant room at DPI: volume of 342 m^3 , acoustical reverberation times of 33 s at 100 Hz and 13 s at 1000 Hz. The floor is covered here by some tested absorbing material.

Further installations were a deep water tank (see below), a nitrogen liquefier and a high vacuum coating plant. The latter two served to support research of hypersound and phonons in solids by Wolfgang Eisenmenger and coworkers [9]. Eisenmenger also constructed a new underwater shock wave generator based on an electromag-

netic principle [10], nowadays used in lithotripter machines. He designed new pressure sensors and determined front thicknesses of shock waves in water and other liquids [11]. For more information on the many works on measurement techniques and metrology at DPI, as well as on electroacoustics, musical acoustics and building acoustics, we refer to [1–4].

3. ROOM AND CONCERT HALL ACOUSTICS

After ample studies on reflectors and diffusers for the improvement of acoustic quality in rooms by Meyer [12], directional diffusivity of the sound field came into focus as a quality measure [13], apart from the reverberation time alone. Figure 3 shows such a directional measurement, performed with a parabolic reflector microphone. It turned out that the clearness of the auditory impression was further determined by the early reflections, and in particular from the side, as later also measured by M. R. Schroeder [14]. Schroeder had already developed in 1954 the statistical theory of reverberant sound fields in rooms, identifying a limit frequency beyond which the acoustic modes overlap and thus can be described in a statistical way [15, 16] – nowadays known as the *Schroeder frequency*. Major studies on concert hall acoustics were conducted by Meyer, Kuttruff, Schroeder and coworkers, and they coined many findings and techniques in room acoustics (e.g., the *Schroeder curve* or *Schroeder reflectors*). For the long-term impact of these studies, see [1, 3]).

4. UNDERWATER SOUND

The Institute housed a larger deep water tank where underwater sound experiments were conducted [17]. The basin was equipped with absorbing walls which allowed for measurements of backscatter from objects. Again, absorbing materials were investigated, here for underwater sound — a branch of Meyer’s research actually dating back to the time before and during WWII. Among many other projects, it was investigated how flat plates radiate sound into water, i.e., how ships radiate sound. Further, it was successfully attempted to discriminate between sonar backscatter signals from metallic objects and those of stone. For this purpose, also simple artificial neural networks had been employed, a pioneering step at the beginning of the 1990s. For a quite detailed list of the underwater sound studies, we refer to [1] and the according chapter by D. Guicking in [3].



Figure 4. Deep water tank of $7 \times 4 \times 4 \text{ m}^3$ for measurements with waterborne sound. The walls of this basin were coated with absorbers effective in the frequency range from 5 to 70 kHz.

5. ULTRASOUND AND CAVITATION

It is impressive to see the early groundbreaking works on ultrasound in liquids and acoustic cavitation, even on sonoluminescence, at Meyer's institute in the 1950s and 1960s. Further seminal studies followed in the later decades until the millenium and beyond, establishing cross-links to fluid dynamics, optics, scientific computing, nonlinear dynamics, and chemistry. The line of cavitation research at DPI is still very active, representing today the inheritance of the Institute's great past in acoustics.

5.1 Cavitation spectra and cleaning

In 1953, Meyer and Skudrzyk [18] studied the sound propagation in bubbly liquids theoretically and experimentally in the ultrasonic regime, and they found quite good agree-

ment for the damping. Already before, Esche had investigated the nowadays well-known acoustic emission spectra of ultrasonic cavitation in a seminal paper [19]. He covered an impressive range of frequencies from 3 kHz to 3.3 MHz and noted in particular the subharmonic of the driving frequency, along with broadband noise, as a characteristic of cavitation emissions. Further, he measured the steep rise of the cavitation inception threshold with frequency, and his data is still actual as a reference. Further theoretical and experimental analysis of acoustic cavitation emission spectra was done by Bohn in 1957 [20]. He discusses in detail the possible origin of broadband noise and concludes that high pressure peaks from bubble implosions are the main source under intense cavitation conditions. As well in 1957, Olaf published an elaborate experimental study of ultrasonic cleaning [21], again for a wide range of frequencies (15 kHz to 2.5 MHz). His results clearly showed for the first time that cavitation is the main agent of the cleaning process, which had only been suspected before: static overpressure could suppress cavitation and at the same time all cleaning effects.

5.2 Bubble collapse: high-speed imaging and simulations

Already in the 1950s, high speed photography was applied to follow the collapse of vapour and cavitation bubbles [22, 23]. The optic and photographic techniques had been developed in the Institute and were at highest standard, reaching 105 000 frames per second with exposure times below 100 ns. The illumination by a sophisticated electric spark method allowed for the imaging of shock waves from collapsing bubbles and bubble clouds. These were as well analysed by fast hydrophones, also constructed and manufactured in-house [24, 25]. Over the years, the frame rates to study cavitation bubbles have been increased up to finally 100 million frames per second [26], elucidating fine details of the amazingly fast and complex process of bubble collapse, see Fig. 5.

As acoustic cavitation bubbles are distributed over three-dimensional volumes, also holography has been applied for recording [27] and extended to high-speed holography with up to 300 000 holograms per second [28–30]. Holograms have been fed into computers to get the 3D size and space distribution. Also stereoscopic recordings of cavitation bubble clouds have been done for getting 3D images of the cloud [31]. A survey has been given in [32].

Today, high-speed imaging is much more common

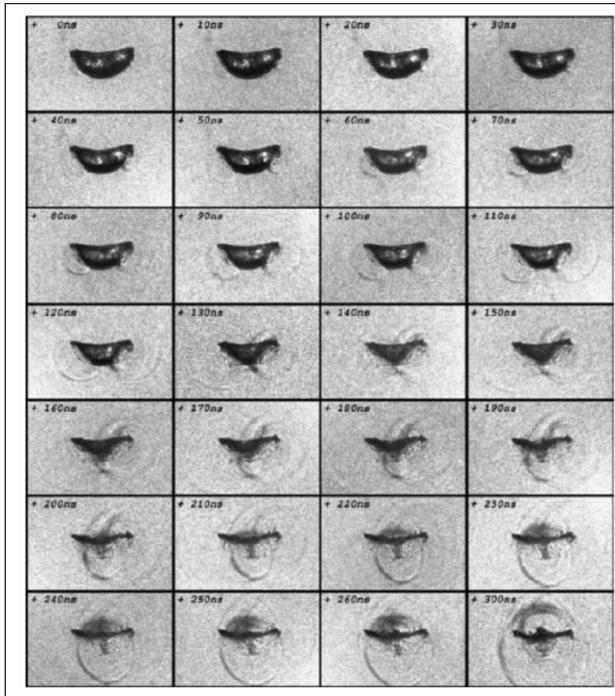


Figure 5. High-speed recording of the final stage of a jetting bubble collapse with its complex sequence of shock waves. The bubble is close to a solid boundary (to the bottom, not visible). Exposure time and framing interval 10 ns. From [26], Copyright Cambridge University Press, 2003.

and a standard technique in cavitation science, forming an important backbone of the research. However, the ever advancing computational resources have established numerical simulations as a second important tool which is quite rapidly growing, both in extension and in potential. At DPI, numerical calculations have been done since the 1960s, still under Erwin Meyer. With respect to sonoluminescence, Kuttruff was calculating collapse pressures and temperatures of collapsing bubbles [33] in 1962, and Strube calculated in an impressive work the shape stability of spherical bubbles and excitation of surface modes in 1971 [34]. Lauterborn added the nonlinear resonance curves of driven bubbles ([35], see below). Since then, bubble and collapse simulations became more and more extended and refined, further surpassing the reproduction of high-speed observations and making predictions of the unresolved and yet unseen. For instance, elaborate Molecular Dynamics simulations have explored the structure of

the extremely heated interior and sonoluminescence of an imploding bubble [36], or expensive CFD studies for bubbles collapsing at solids have predicted new jetting modalities with jet speeds in the range of 1000 m/s [37], later also seen in experiments at DPI and at other groups.

5.3 Optic cavitation

In the course of adding coherent optics to the research topics at DPI, Lauterborn, his scholar Vogel, and coworkers investigated the focusing of intense laser pulses in liquids [38]. Once the electrical breakdown threshold is crossed, a hot plasma spot is created, and a bubble expands which subsequently collapses. This phenomenon, termed optic cavitation, served subsequently as an ideal tool for cavitation studies and allowed for detailed investigation of bubble jetting [39] and further collapse dynamics [40], shock wave emissions [41], or material damage [42]. Optic cavitation is nowadays a standard technique, and the early and seminal contributions at DPI opened up the path to many important applications of lasers far beyond acoustics, for instance in eye surgery and material processing.

5.4 Nonlinear Dynamics

For several reasons, the investigation of acoustic cavitation provoked the preoccupation with nonlinear systems. One side was the sound propagation of finite amplitude waves in liquids and in particular under presence of bubbles [18]. But at the heart of cavitation lies the dynamics of bubbles which is intrinsically nonlinear. In 1956, G uth published an analytic approach to the nonlinear oscillations of harmonically driven spherical bubbles [43]. He demonstrated that subharmonic solutions exist if the bubbles are driven above (linear) resonance, as known for other nonlinear driven oscillators, and he suggested such solutions as a source of the subharmonic components in acoustic cavitation spectra. The numerical approach by Lauterborn from 1973, finally published in 1976, highlighted the richness of possible dynamics of strongly driven bubbles [35]. Among nonlinear resonances and hysteresis, the study showed that also bubbles driven below the linear resonance can oscillate at higher periods. This can happen near ultraharmonic resonances, a case much more commonly met in acoustic cavitation. Furthermore, indications for chaotic (non-periodic) solutions had been given. These have been later confirmed and much more elaborated in the framework of bifurcation analysis, for instance by Parlitz [44]. This stimulated many more fundamental investigations of nonlinear sys-

tems at DPI, extending on different and coupled nonlinear oscillators, but also on methods for nonlinear system analysis, time series prediction, synchronization, and more.

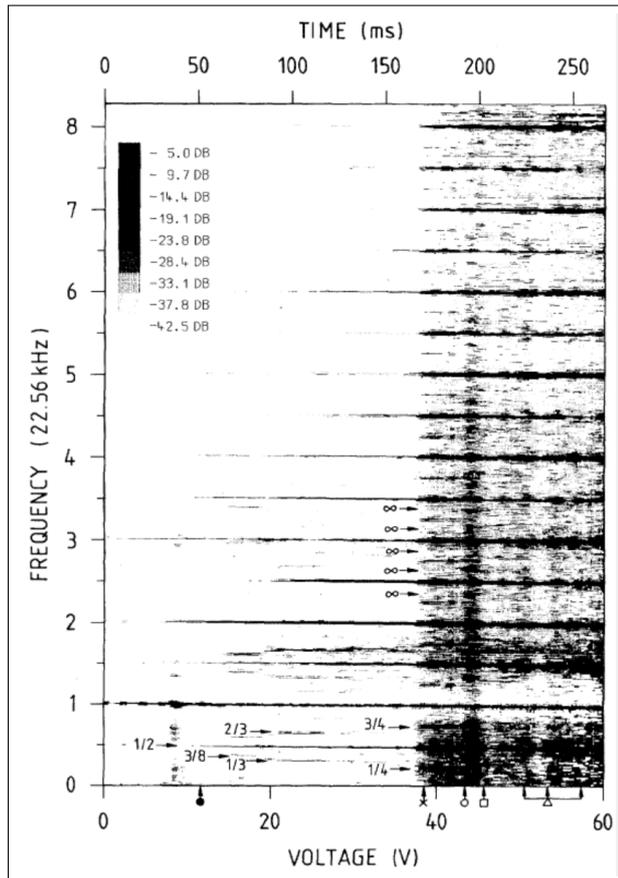


Figure 6. Spectral bifurcation diagram: The driving voltage of the transducer is linearly increased from 0 to 60 V in 256 ms. From [45]. Copyright: American Physical Society, 1981.

Experimentally, the subharmonic cavitation spectra and the according bubble oscillations had been investigated by Lauterborn and coworkers more closely. Employing an upward ramping of the driving pressure, a period doubling cascade could be identified [45] as shown in Fig. 6. This lead to the conjecture of chaotic dynamics in developed acoustic cavitation, one form of "acoustic chaos" or "acoustic turbulence". Imaging of the bubbles revealed that full bubble structures can oscillate in a period doubled fashion [46], and it has been confirmed in later studies that indeed a low-dimensional dynamics can

be dominant [47]. Today, the topic of acoustic cavitation spectra is still under investigation, one application being the diagnosis of ultrasonic cleaning systems.

5.5 Sonoluminescence

Meyer, Kuttruff and coworkers clarified already end of the 1950s that bubble collapse and sonoluminescence light emission happened synchronously, a fact that was disputed at that times. The correlation was shown first by phase related imaging of bubbles and registration of light [48,49], later with an ingenious method and much higher precision by coincident measurement of shock waves and light [33]. As origin of the light, the "hot spot" in the collapsed bubble was correctly advocated and corroborated by these works, but nevertheless, many other theories circulated until the millennium. Quite remarkable are also the experiments by Schmid, who in 1959 observed single bubble collapse luminescence in an arrest tube setup [50]. Later, he investigated the influence of the filling gas on the light emission of imploding hollow glas spheres in different liquids, favouring krypton in glycerine [51]. Research on sonoluminescence continued at DPI and is still active today, investigating many more details and possibly having realised one of Meyer and Kuttruff's dreams, namely to directly see bubbles collapsing and flashing in an acoustic cavitation bubble field, as shown in Fig. 7 [52].

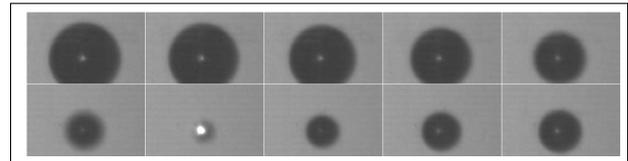


Figure 7. Collapse of a xenon bubble in phosphoric acid, driven at 23 kHz and recorded at 525 kfps. The sonoluminescence flash is seen on the 2nd frame, bottom row. (Courtesy: C. Cairós; see also [52])

6. CONCLUSIONS

Only a few topics from the vast amount of acoustic work in Göttingen could be addressed. Most of them root in the pioneering works done under the auspices of Erwin Meyer since 1947. It can be rightly stated that his school had a great influence on the acoustics research in Germany, Europe, and possibly worldwide, and it was — and still is — perpetuated by many former DPI scholars in own research groups at other institutions.

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THE INSTITUTE OF TECHNICAL ACOUSTICS AT THE TECHNICAL UNIVERSITY OF BERLIN – A FOUNDATION AT THE RIGHT TIME AND PLACE

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ABSTRACT

Starting from and continuing multiple previous efforts to investigate the physics of vibrations and waves in Mechanics and Acoustics at the Institute of Mechanics of Technical University Berlin (TUB) and the Heinrich-Hertz-Institute (HHI) in Berlin, in 1954 the Institute of Technical Acoustics at TU Berlin was founded. In close agreement with the profile of its highly regarded founding director, Lothar Cremer, the Institute aimed at exploring, developing and providing engineerable approaches, methods and technologies to control sound and vibrations as well as at deepening the understanding of underlying physical mechanisms. Being well equipped with both, a growing number of highly qualified academic staff members and modern, state of the art installations and utilities, the Institute soon belonged to the highly respected key institutions of its kind in Germany and Europe.

This development was essentially driven by acoustic requirements for fast reconstructions and later for growing comfort expectations which more and more turned acoustics to an important interdisciplinary field of modern science and technology. The paper reviews the driving forces of this development as well as the results of the Institute's work which was greatly influenced by its directors Lothar Cremer and Manfred Heckl.

Keywords: *History of Acoustics, Engineering Acoustics, Technical Acoustics, Lothar Cremer, Manfred Heckl.*

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1. INTRODUCTION

Based on its long tradition in both, groundbreaking research results (e.g. Hermann von Helmholtz) and pioneering industrial developments (e.g. Werner von Siemens), the vibrant city of Berlin provided - in the first half of 20th century - an inspiring, state-of-the-art environment for further developing and applying the discipline of Acoustics.

At that time, after the comprehensive works of Lord Rayleigh and Helmholtz, Acoustics was seen to be well understood, not needing more basic research. However, driven by the need to better understand all aspects of acoustics to improve the quality of newly introduced (1923) broadcasting, several national authorities combined their support to promote further targeted investigations in Berlin. Prominent protagonists of these were Erwin Meyer and Lothar Cremer who - by the success of their work - had formative influence on substantial and institutional alignment of acoustic research in Berlin. Since 1929, they maintained continuous research and teaching in the field of applied acoustics at the Institute of Mechanics at Berlin's "Technische Hochschule" (TH, Technical University). These activities were complemented and extended by the young Heinrich-Hertz-Institute (HHI) for Vibration Research, founded in 1929. Here, one of four departments (led by Erwin Meyer) was uniquely devoted to research in Technical Acoustics. Thus, although being subordinated to institutes of mechanics and vibration research, Acoustics was well established and supported as an autonomous discipline of acknowledged relevance.

After the disastrous destructions of World War II, new formation of the then so-called Technical University (TU) of Berlin led to the explicit foundation of an Institute of Technical Acoustics (ITA) which, together with the ongoing work of HHI, was devoted to cope with growing demands in the area of applied Technical Acoustics.



This paper reviews the foundation of ITA in 1954 and traces its successful, most influential work in the second half of 20th century, i.e. up to the year 2000. In doing so it widely follows the valuable collection of historical facts and materials compiled by Peter Költzsch in [1].

2. ACOUSTICS AROUND 1950

By the beginning of the 20th century, scientific understanding of physical acoustics was highly developed and fixed in advanced, comprehensive theories, Helmholtz' "On the Sensations of Tones" (1862) and Lord Rayleigh's "Theory of Sound" (1894/96) being the most prominent ones. A little later only, the compilation of "Methods of Mathematical Physics" (1924) by Courant and Hilbert then had provided a rigorous mathematical treatment of the underlying physical correlations.

In parallel to the scientific exploration of physical acoustics, the end of the 19th and the first decades of the 20th century saw a rapid development of electroacoustic technologies to transduce, register, transmit, reproduce and - finally - broadcast sound. Apart from improving the sound quality of recorded (disc and tape) and transmitted (via phone and radio) sounds, Sabine had laid the foundation for targeted design and layout of auditory rooms to best adapt them to speech and music.

In addition to providing and improving desired sounds, control of undesired sounds also had become an issue which had caused first systematic investigations of particular sound generating, sound transmitting and sound controlling mechanisms ([2]). Prominent examples were

- Berger's mass law (1910) and the
- derivation and experimental verification of the coincidence effect by Cremer and Eisenberg (1942/48).

Together with the development of versatile measurement devices and adjusted assessment units (like "dB" and "phon" in the 20s), Technical Acoustics had become a discipline ready to serve new technical possibilities (electroacoustics), quality-conscious hearing requirements (room acoustics) and sound reduction requirements (noise control): Technical Acoustics was to become Engineering Acoustics.

3. THE INSTITUTE OF TECHNICAL ACOUSTICS AT THE TECHNICAL UNIVERSITY OF BERLIN

3.1 Foundation

As mentioned earlier, the discipline of acoustics had been taught at TH Berlin since 1929, when Erwin Meyer had become Director of the acoustic department of HHI and

lecturer (1929-1934) or professor (1934-1945) for Technical Acoustics at the Institute of Mechanics/Vibration Research of TH Berlin. With the resources of HHI, TH Berlin was the first German university providing a lab exclusively devoted to teach and research acoustics. Supported by Lothar Cremer, who worked with Erwin Meyer at HHI and TH and, from 1940 to 1945, also gave lectures on acoustics in the field of Mathematics and Mechanics at TH Berlin, the group obtained important research results and thus soon was able to establish its excellent reputation.

Both, TH Berlin and HHI could not escape dreadful appropriation by the National Socialist regime and the resulting discrimination and expulsion of Jewish and critical scientists and students. However, being bewared, all in all, of direct military research and development tasks, the pre-war and war years allowed mainly focusing on purely scientific problems. Among these, basic water-borne sound projects saved the staff members from being sent to the front. But by the end of the war, the buildings and labs of Acoustics lay in ruins.

After the new opening of TH as Technical University (TU) in 1946, it was obvious to take up, as soon as possible, the successful scientific tradition of acoustics in the thirties and forties. However, general confusion and great destruction of war made any coordinated resumption of activities very difficult. It thus took until 1954 that the University came to a clear decision by closing down its own Institute of Vibration Research and founding the new Institute of Technical Acoustics together with a professorship of the same name. By April 1, 1954, Lothar Cremer was appointed to serve as both, Professor for Technical Acoustics and Director of the Institute.

Meanwhile, HHI was able to overcome its previous separation into a western and an eastern part and to restart on Oct. 1, 1955, its activities as a non-university research institution being supported by a sponsoring consortium. In spite of its organizational separation, the institutes of HHI were closely interlinked with the corresponding institutes of TH and headed - in personal union - by their respective directors. Thus, Lothar Cremer also became head of the HHI Department of Acoustics.

3.2 Institute Facilities and Resources

In spite of generously concluded appointment negotiations, the newly founded institutes had to suffer provisional offices and facilities, the more as all excellent equipment of HHI had been destroyed in the war. It took until the sixties that the institute was freed from the tight situation at Jebenstraße by moving to optimal new lab facilities at Einsteinufer - in direct proximity to the new HHI building which opened a

few years later only. Here, the institute could use all state-of-the-art test and measurement facilities, including large absorbing and reverberation chambers, basins for water-borne sound, building and flow acoustic test stands and large premises for flexible test installations to comply with later requirements. In addition, the institute was given a well-equipped mechanical workshop as well as up-to-date measurement and computational equipment together with appropriate workshops for its maintenance.

From the very beginning, the ITA staff consisted of three groups of scientific employees: research assistants directly funded by the university, research assistants supported from external funds and members of the scientific staff of HHI whose acoustic department, until 1974, was led in personal union by the ITA director. This academic staff was complemented by qualified colleagues to serve and operate all technical equipment and workshops and to provide technical drawings and secretarial support.

Other than the members of the above mentioned non-professorial academic staff, who typically were employed along a strict time limitation scheme only, the lack of time limitations allowed professorial staff members to plan and implement long-term targets and strategies. In its first 50 years, this orientation mainly was given by the directors of the institute, Lothar Cremer (1954-1972) and Manfred Heckl (1973-1995). But other professors and lecturers were able also to effectively influence teaching and research of the institute: Prof. Ernst Lübke teaching noise abatement from 1955 to 1967 already, Prof. Matthias Hubert teaching and researching on various fields of Technical Acoustics from 1958 to 1993, Prof. Jürgen Gruber focusing - together with and followed by Prof. Christian Maschke - on assessing noise effects with special emphasis on sleeping disturbances and - since 1991 - Prof. Michael Möser complementing and extending the institute's research area by the fields of theoretical acoustics and structural dynamics and active sound control.

In recognition of the dominant guidance and orientation given by the institute's directors, the following overview is structured into two sections covering the periods of Lothar Cremer and Manfred Heckl.

3.3 Period of Lothar Cremer (1954-1973)

3.3.1 Brief Life Story of Lothar Cremer

Lothar Cremer was born in Munich on August 16, 1905, 9 years before the outbreak of World War I at a time where Germany still was an empire. He was the youngest child of Max and Elisabeth Cremer. The Cremers were a family of scientists: Lothar's father Max was a professor of animal

physiology, his brother Hubert later became a professor of mathematics and his sister Erika a professor of physical chemistry. Also, Lothar Cremer's son Michael pursued an academic career later.

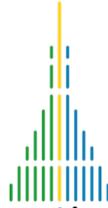


Figure 1. ITA Directors Lothar Cremer (left, 1954-1973) and Manfred Heckl (right, 1974-1995).

In 1911, the Cremer family moved to Berlin where Lothar's father Max had been appointed to the city's university. After a temporary stay of his family (at the end of the war in 1918) in Bavarian Sielenbach, Lothar Cremer passed his high school graduation (Abitur) in 1923 in Berlin. He played viola, violin and piano and initially was undecided whether to start a career in music or engineering.

For that reason, he first worked at a training school of AEG, a large general electricity company. Only then he decided to take up studies in general mechanical engineering first and electrical engineering later at TH Berlin. He received his diploma in 1930. His diploma thesis "*Zur Theorie der Frequenzabhängigkeit eines Wechselstromkreises mit Gleichstromgerät und Trockengleichrichter*" (On the theory of frequency dependency of an AC circuit with a DC device and metal rectifier) was supervised by Franz H. Ollendorff at the Institute of Theoretical Electrical Engineering.

Lothar Cremer then was doctoral student at the AEG Research Institute where he worked with Carl Ramsauer, Director of AEG Research and honorary professor at TH Berlin. In 1933, a few weeks after Hitler's rise to power only, he received (with summa cum laude) his doctoral degree for his dissertation "*Experimentelle und theoretische Untersuchungen über die Abhängigkeit der Schallabsorption vom Einfallswinkel bei porösen Wänden*" (Experimental and theoretical studies on the dependence of sound absorption from the angle of incidence to porous surfaces) which was supervised by Carl Ramsauer and Erwin Meyer (TH and HHI).



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Later in 1933, Lothar Cremer then worked on structure-borne sound problems at the HHI department of acoustics (headed by Erwin Meyer) and, from 1934, also at the Institute of Mechanics of TH Berlin (as senior engineer). There, on March 27, 1936, he qualified as professor by his post-doctoral thesis (Habilitationsschrift) “Neue Methoden der absoluten Messung der Schallschluckung bei schrägen Einfallswinkeln“ (New methods for absolute measurements of sound absorption at non-orthogonal angles of incidence). Later, from 1940 to 1945, Lothar Cremer gave regular lectures at the Institute of Mechanics

Although following up a variety of topical issues (e.g. control problems for torpedo guidance systems), Cremer’s work continuously focused on the phenomenon of trace matching between an incident wave and a bounding structure (the then so-called coincidence effect). In 1942, this work resulted in his pioneering paper “Theorie der Schalldämmung dünner Wände bei schrägem Einfall” (Theory of sound insulation of thin walls at oblique incidence) being published in the “Akustische Zeitschrift” (Acoustics Journal). Its content is still part of the basic knowledge of any building acoustics engineer today.

Lothar Cremer and his family were bombed out twice and suffered the loss of almost their entire household. So, towards the end of the war, his family once more ended up in Sielenbach, Bavaria, where he still was able to use facilities at Lake Starnberg to continue his consulting activities for German Navy on questions of underwater acoustics and structure-borne sound insulation.

Soon after the end of war, the British occupation force - initiated by Erwin Meyer - asked Lothar Cremer to put together his recent works on structure-borne sound in vehicles and buildings. The result was the monograph entitled “Propagation of Structure-Borne Sound” which provided the basics for his later book on “Structure-Borne Sound” (co-authored by Manfred Heckl).

In Munich, Lothar Cremer moved into the house of his parents and soon took up two activities in parallel: In 1946, the American occupation force granted him the authorisation and business license to run a consulting engineering office. In addition, he received a teaching position as lecturer (1949-1951) at both, the Technical and the General Ludwig Maximilian University (LMU) in Munich, where he later was appointed adjunct professor (1951-1953).

Although his lectures were ambitious, Lothar Cremer knew how to inspire those students who followed until the end. He was able to point out that in spite of its physics being well understood, acoustics still has left open many questions of theoretical and practical interest.

In one year, among his students he found Manfred Heckl, Helmut Müller and Matthias Hubert who all accompanied

and continued his academic and consulting work for many decades. This cooperation was started by employing the school friends Manfred Heckl and Helmut Müller as student assistants in his private acoustic lab, the “Akustisches Laboratorium”.

Apart from many smaller projects, the acoustical design of a new concert hall (Herkulesaal) to be built within the reconstructed Munich Residence was a major task for Lothar Cremer and his team. Based on thorough analysis and measurements, the hall finally provided well balanced acoustics for multiple use with high sound isolation for studio recordings. This was achieved by combining proven approaches like improved prediction of absorbing elements (seats and carpets) or innovative measures like the worldwide first application of freely suspended reflectors.

Although running a successful consultancy, the highly respected researcher Lothar Cremer could – in longer terms - not withstand a continuation of his equally successful academic career. It thus was a fortunate but also logical coincidence that the initiative of TU Berlin to establish a new institute and professorship for Technical Acoustics found and appointed Lothar Cremer to be the founding professor and director of this institute.

So, together with his future senior engineer Manfred Heckl, Lothar Cremer in 1954 moved to Berlin and started his fruitful activity at the ITA of TU Berlin and HHI. Helmut Müller was planned to follow him later after having completed and concluded all current orders and contracts. Helmut Müller’s failure in doing so prevented him from joining Lothar Cremer and Manfred Heckl in Berlin. On the contrary, his ongoing and promising business in Munich finally caused him to successfully continue it in a newly founded company, today’s Müller-BBM AG (see [3] for more details). In contrast to him, Matthias Hubert later also became senior engineer and professor at ITA in Berlin.

To complete the life story of Lothar Cremer, it must be mentioned that he received two high-ranking awards. In 1970 he was elected a full member of the Göttingen Academy of Sciences and in 1989 he was honoured with the Gold Medal of the Acoustical Society of America, ASA.

In the years after his retirement, Lothar Cremer lived in Miesbach, Bavaria, where he died on Oct.16, 1990.

3.3.2 Activities, Achievements and Impact

Lothar Cremer definitely was one of the last great personalities who were able to overlook and understand the many details and partial aspects of present acoustics together with their intercorrelations. However, although being interested in almost all fields of Technical Acoustics, he put particular emphasis on Physical Acoustics, Musical Acoustics,

Architectural (room and building) Acoustics, Structure-Borne Sound and Acoustical Measurement Technology. This can be verified in retrospect by the multiplicity of research topics he and his colleagues addressed since his appointment in Berlin. It also can be verified by the spectrum of topics he was able to enrich with new fundamental findings and comprehensive review literature. For the purpose of this review, this may be illustrated by some exemplary examples only.

Lothar Cremer himself considered three achievements as his most important contributions to science:

- general significance of the in-phase wave train closure principle which states that a natural (eigen-)vibration (resonance) occurs if a propagating wave after reflection at all boundaries along its path returns to its starting point with the same phase.
- coincidence (trace matching) effect, stating full sound transmission for a thin lossless plate if the trace wavelength of an incident airborne wave and the bending wavelength of the plate match.
- derivation of orthogonality and reciprocity from the reciprocal energy theorem. As Manfred Heckl showed later, this general theorem allows the derivation of extended reciprocity relations which, on their part, can be used to define indirect measurement procedures for air- and structure-borne sound sources in linear mechanical systems.

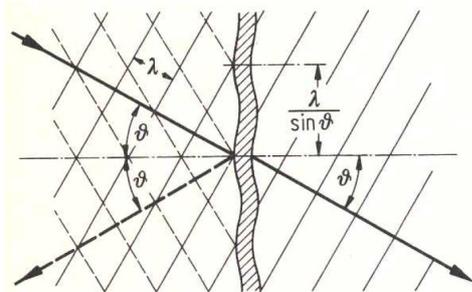


Figure 2. Original sketch to illustrate coincidence as match of airborne trace- and bending wavelength.

From a historical distance it can clearly be stated that the thematic scope of Cremer's most relevant contributions by far exceeds the three topics he mentioned himself. Instead of being listed in terms of particular findings and results, this may be illustrated here by a small but representative selection from his major publications:

- Lecture Notes on Technical Acoustics (co-authored by M. Hubert, continued by M. Möser) ambitious, didactically consequent introductory text-

book to a broad spectrum of acoustic principles and applications

- Structure-Borne Sound (co-authored by M. Heckl, translated by Eric Ungar) prospective introduction and treatment of structural vibrations and sound radiation at audio frequencies,
- Principles and Applications of Room Acoustics in three volumes covering geometrical (1), statistical (2) and wave-theoretical (3) room acoustics comprehensive introduction, discussion and state-of-the-art conclusion of all aspects of room acoustics in both, theory and applicative practice,
- Physics of Violin (1981,1984) extensive monograph of the author's intensive research and scientific discussion on many physical phenomena and aspects of the violin and its playing.

Apart from this written heritage, one widely known example of Lothar Cremer's tangible heritage shall also be mentioned: the new Philharmonic Hall of Berlin, opened in 1963. This initially controversial (but style setting later) design of architect Hans Scharoun has developed to a reference as spatially inviting hall with arena-like orchestra setting amidst the audience. But it also owes its popularity to the inventive implementation of innovative room acoustic measures. In particular, the consequent introduction of stepped (vineyard) audience blocks improving direct sound supply and providing additional early reflection surfaces has essentially contributed to overcome the inherent difficulties with centered orchestra settings.

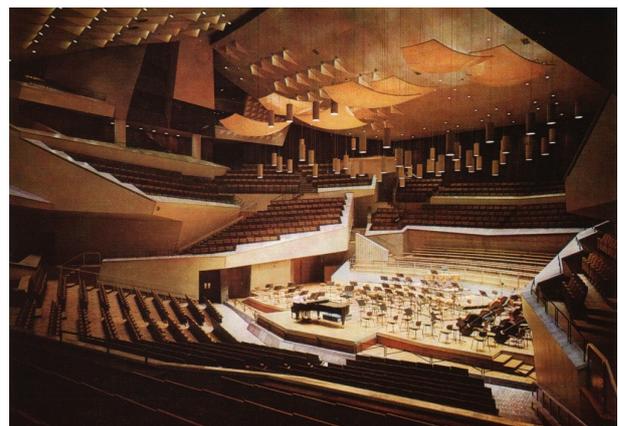


Figure 3. Berlin Philharmonic Hall.

Lothar Cremer has been a most influential researcher, initiator, supervisor and teacher who, by his own work as well as by the work of his assistants and research groups, has created and established an acoustic school – a school in picking

up contemporary technical challenges and, above all, in developing engineering methods and methodical approaches. Numerous student research and diploma theses, doctoral theses/dissertations and many comprehensive research and study reports summed up to outstanding progress in further developing technical acoustics and in applying it to engineering solutions - to engineering acoustics. Having laid important general foundations of engineering acoustics and having derived exemplary approaches and findings in architectural acoustics, it now was up to the next generation of the institute to address subsequent tasks in technical and engineering acoustics, among them the prominent challenge of industrial and transportation noise control.

3.4 Period of Manfred Heckl (1973-1995)

3.4.1 Brief Life Story of Manfred Heckl

Manfred Heckl was born on July 15, 1930, in Renertshofen, Bavaria. His exceptional talents were obvious when he was a schoolboy yet and student later. He amazed by excellent work and by his phenomenal memory which surprised others many times again till the very end. During his studies of physics in Munich he came – together with his school friend Helmut Müller – across the very right teacher, the lecturer Lothar Cremer whose lecture on acoustics was able to fascinate and permanently bind the two friends to this discipline.

In 1954, Manfred Heckl completed his studies of physics with an experimental diploma thesis on sound bridges at floating floors. He then followed his teacher Lothar Cremer as scientific assistant to the just founded Institute of Technical Acoustics at the Technical University (TU) of Berlin. There, he graduated in 1957 with a PhD thesis on sound radiation and attenuation of cylindrical shells.

During his time at ITA in Berlin he also started his family. He married his wife Anna in 1956 and became a father of five children until 1964. His eldest daughter Maria followed his professional example and today does scientific research and teaching as Professor of Engineering Mathematics at Keele University in the UK.

After three years in the US, where he was with the reputable acoustic consultancy Bolt, Beranek and Newman, BBN, he returned to Germany in 1962 to start the German consultancy Müller-BBN in Munich together with his old friend Helmut Müller, his teacher Lothar Cremer, Ludwig Schreiber and the Engineering Consultancy BBN from the USA, represented by Leo Beranek.

Manfred Heckl has essentially contributed to shape this acoustical consultancy. His influence was formative in both, technical and economic matters. His profound understand-

ing of physical and mathematical issues was the ideal basis for many novel approaches to solve the variety of new problems in practical engineering acoustics. His achievements and experiences were compiled in many technical reports. Among these he authored a comprehensive survey on generation and control of flow-induced noise which qualified him as post-doctoral lecturer (“Habilitation”) in 1973. He thus best recommended himself to be reappointed for the chair of Lothar Cremer who had been given emeritus status in 1972.

To complete the life story of Manfred Heckl, it must be mentioned that he received two high-ranking awards. In 1992 he received the Rayleigh Medal of the British Institute of Acoustics (IOA) and in 1997 he was honoured posthumously with the Helmholtz Medal of the German Acoustical Society (DEGA).

Manfred Heckl had many plans for the time of his retirement where he wanted to return to Munich and to work with Müller-BBN again. But this was not to happen, he died on August 16, 1996 from the complications of a brain surgery.

3.4.2 Activities, Achievements and Impact

In the mid of 20th century when Manfred Heckl decided for his branches of acoustics, these acoustics were at the beginning of a period which more and more was to be characterized by problems of avoiding or reducing sound. Avoiding, controlling sound, however, can be done the better, the more its generation is understood. Consequently, all interest was directed to those phenomena which preceded the propagation of existing air-borne sounds: the generation of sound in gaseous and liquid media with and without flow and the excitation, propagation and radiation of structure-borne sound.

Manfred Heckl’s profound knowledge of fluid and structural dynamics was the starting point for pioneering works. These works first thoroughly investigated the relation between the excitation of flat structures and the corresponding sound radiation and later then dealt with establishing and introducing statistical energy analysis, SEA. Other focusses of later research work were:

- description and numerical treatment of wave fields in coupled structures, inhomogeneous and layered media
- generalization and application of the reciprocity principle,
- investigation of complicated sound generating mechanisms, in particular for rolling noise on roads and rails,
- illustrative visualization of complex acoustical fields even in many, partly brilliant films

Apart from the development of important new methods, the greatest merit of Manfred Heckl may be seen in his exemplary application of theoretical insight to the numerous problems of acoustics in practice. To get there, numerical approaches always have been an aid, a tool to him but never a method by itself. As aid, however, he intensively used numerics. For this purpose, he was equipped in the 60s already with the first private terminal installed in Germany giving on-line access to a mainframe computer in the US.

The Heckl-specific mixture of phenomenal physical intuition, application-oriented ability to think in abstract terms and perfect mastery of mathematical methods for computation and approximation allowed him - apart from exact solutions - to find many useful and practicable formulas for estimation and prediction of acoustical parameters and field quantities. He thus really had an absolute vocation not only for further developing the current state of knowledge but also to apply it to practical problems, to make it available to the daily work of acoustic engineers.

Both, his preference for formulating, evaluating and approximating theoretical approaches as well as his continuous reference to practical problems are ideally summarized in an aphorism which he often liked to quote:

There is nothing as practical as a correct theory.

This motto best characterizes his approach and is exemplarily implemented in the famous book, “Körperschall” (Structure-Borne Sound, 1967), written together with Lothar Cremer based on Cremer’s earlier monograph. This book forms a perfect and exemplary symbiotic relationship between these physical basics and their technical applications. A few books only manage to be labelled as a “bible” - being indispensable for both, introduction and reference, over a long period of time, and successfully bridging the gap between the ways of thinking in acoustics and continuum mechanics/structural dynamics.

Other important and recognized books were and are the “Taschenbuch der Technischen Akustik” (1975,1994), edited together with Helmut Müller and written together with many German colleagues to compile all relevant information, knowledge and tools of the time and thus to successfully apply engineering acoustics to the many practical problems. A later, updated version has been edited in English as “Handbook of Engineering Acoustics” (2013).

Again, as for Lothar Cremer before, the far-reaching impact of the achievements of Manfred Heckl together with his many assistants and research groups go beyond the scope of this survey. Instead, some major achievements shall exemplarily demonstrate both, the methodological continuity as well as the topical adaptability of the Berlin school of Technical Acoustics:

- systematic investigation and description of air-, fluid- and structure-borne sound generating mechanisms;
- systematic investigation, classification and guidance to understand and control generation and transmission of structural vibrations and waves and their radiation as air-borne sound waves from vibrating structures; Apart from providing rules and tools for a variety of typical applications, the engineer-oriented consideration of structural and structure-borne phenomena and methods opened a completely new perspective to technical and engineering acoustics;
- systematic application of insight into structural dynamics and radiation to analyze typical building constructions and to predict the effect of control measures in building acoustics;
- basic investigations and triggering impulses for comprehensive research efforts and programs to understand and model the generation of rolling noise and vibrations; Seen from today, these activities were able to create crucial basics for a useful rolling noise generation model which successfully has been used later to identify influential rolling noise parameters and to predict their influence on controlling the rolling noise of both, road/tyre and wheel/rail interaction.

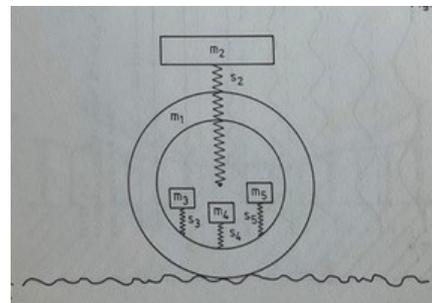


Figure 4. Early sketch of simplified parametric rolling noise generation model by M. Heckl.

When initiating and following up working topics, Manfred Heckl did not follow his personal interests only. Instead, he always tried to extend the working spectrum of his institute. As an example, he initiated early investigations on active control of vibrations and waves.

Apart from his research activities, Manfred Heckl’s teaching activities have also left clear traces. His main lectures dealt with Theoretical Acoustics, Structure-Borne Sound, Flow Acoustics, Noise Abatement and Traffic Noise. With these lectures Manfred Heckl introduced a new formal tradition which was characterized by a clear and systematic theoretical basis. This included the concept of general

mechanics as well as a consequent treatment of advanced mathematical tools. The lectures also were characterized by high clarity and by many instructive experiments to illustrate the basics of acoustics.

All in all, Manfred Heckl continued and - in the sense of his time - completed transition to and establishment of engineering acoustics. Focusing on engineering architectural (building and room) acoustics in the immediate after-war years was consequently followed by focusing on the most relevant side effects of mechanization and industrialization: industrial and transportation noise. Having essentially contributed to identify and control flow-induced noise as an important source of industrial noise before he was appointed professor of Technical Acoustics in Berlin, he then initiated and pushed forward successful research work for effectively controlling rolling noise as major source of transportation noise. Thus, when Manfred Heckl was given emeritus status in 1995, his Institute of Technical Acoustics had essentially contributed that engineering acoustics was well developed and established to cope with the challenges of time.

3.5 Following Periods (after 1995) and Outlook

The early death of Manfred Heckl had left the institute with the task to maintain its competence and reputation while adapting its profile to changed needs and requirements. Acoustics had become an established engineering discipline, putting more emphasis on application-oriented research and development than on the self-related exploration of new approaches. Consequently, the number of acoustic institutions specially dedicated to other disciplines like architectural, civil, mechanical or automotive engineering had increased at the expense of previous institutes of cross-applicational competence.

However, the overlapping continuity provided by Michael Möser was able to preserve and transfer the proven spirit of the institute into the new century, where the institute managed to successfully complete the generation change with the new professors Björn Petersson, Enno Sarradj, Brigitte Schulte-Fortkamp and André Fiebig and thus to cope with new demands.

4. SUMMARY AND CONCLUSIONS

In direct continuity to the tradition of technical/scientific acoustics in Berlin, the foundation of the Institute of Technical Acoustics at TU Berlin ideally met the challenges of its time: to provide new, urgently needed insight and approaches for integration of acoustic aspects into engineering processes. The Institute soon turned out to be best posi-

tioned for this. Its directors Lothar Cremer and Manfred Heckl both were able to set and inspire well-targeted perspectives and to win, motivate and guide excellent teams to follow them with great success.

By its outreach, by the wide range of results as well as by the qualification of its research assistants and graduated students, the Institute essentially contributed to establish engineering acoustics as a powerful, indispensable engineering discipline. Engineering Acoustics thus had become the driving force of the renaissance of acoustics after 1950.

5. ACKNOWLEDGMENTS

It hardly can be emphasized enough to what extent historic reviews like the one given here depend on the most valuable collection of materials edited by Peter Költzsch in his series of publications on the history of acoustics. The authors particularly appreciate and recommend the comprehensive information given in volume 10 of the series. ([1]). They also would like to express their gratitude to many former colleagues for remembering and contributing details from their personal experience.

Finally, both authors highly appreciate the opportunity to express - by this review article - their admiration and gratitude for the work and guidance they received from the Institute of Technical Acoustics at TU Berlin and - in particular - from their outstanding personalities, Lothar Cremer and Manfred Heckl. They both impressively extended, embodied and shared the great fascination acoustics has for acousticians and the relevance it has for the comfort of life and the preservation of our environment.

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TURNING AND PROVIDING ACOUSTICS TO ENGINEERING PRACTICE - FOUNDATION AND EARLY DEVELOPMENT OF MÜLLER-BBM IN GERMANY

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ABSTRACT

After repeated efforts and achievements in applying physical understanding of acoustics to practical applications before the 1950s, the sharp increase in needs of acoustical guidance for massive reconstructions after World War II suddenly required both: advanced scientific insight and advanced skills and experience in its practical implementation. This was the natural starting point for professional acoustic consultancy start-ups, ideally as spin-offs from proven scientific units.

It was exactly this coincidence of technical and social requirements and high technical/scientific skills and potential which, in Germany in the 1950s, led to the foundation of a small office which later, since 1962, was operated as Müller-BBN and, since 1974, as Müller-BBM GmbH. The names of the founders themselves were program: Leo Beranek (with BBN), Lothar Cremer and his students Helmut Müller, Manfred Heckl and Ludwig Schreiber stood, from the very beginning, for further developing and applying latest state-of-the-art acoustics to the many practical challenges of the time.

The paper reviews the driving forces, the development and the achievements of Müller-BBM from the very beginning through the first decades to one of the leading engineering companies in acoustics and environmental technologies and planning then and today.

Keywords: *History of Technical Acoustics, Mueller-BBM, Lothar Cremer, Helmut Müller, Manfred Heckl*

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1. INTRODUCTION

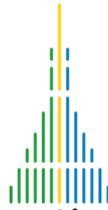
Although its long and successful tradition in acoustic research had placed and kept Germany in the forefront of scientific and applied acoustics, in the mid of 20th century this physical discipline suffered the image of being mostly explored and conclusively understood, thus lacking the fascination of new challenges. However, this outer appearance should not mislead about successful efforts to better understand acoustics for various occasional problems, particularly in electroacoustics, room acoustics and, in the years of war, marine applications.

Nevertheless, it likely was preserved to exclusive insight of insiders only to anticipate the relevance of acoustics for future technical progress. The well-respected German acoustician Lothar Cremer belonged to them. From him it is reported that in one of his early lectures he had predicted that the task of future physicists was not so much to make new discoveries and developments but the more to cope with negative consequences of existing technologies - long before terms and concepts of environmental protection have been introduced.

Lothar Cremer was to be right. The years of fast reconstruction and rapid mechanization after World War II together with growing demands for environmental compatibility and better quality of life finally turned acoustics into an indispensable engineering discipline. This can be ideally exemplified by reviewing pre-history, foundation and development of Müller-BBM, an engineering consultancy which, at the same time, successfully managed both: to be continuously driven by technical needs as well as to drive forward necessary acoustic know-how.

This paper will review the foundation of Müller-BBM in Munich, Bavaria, and trace its successful development in the second half of 20th century, widely following the valuable references given in [1] and [2].





Since the very roots of Müller-BBM are found in the private consulting activities of Lothar Cremer, the paper also is linked to his further heritage, the Institute of Technical Acoustics (ITA) of Technical University of Berlin (TUB). In fact, both institutions continued the business Lothar Cremer had started immediately after World War II: his research and teaching activities which led him from an adjunct professorship in Munich to the appointment as professor and founding director of ITA in 1958 and from his private research and consulting activities to co-foundation and promotion of Müller-BBM. More details on Lothar Cremer and the history of the Berlin Institute of Technical Acoustics can be found in a companion paper ([3]).

2. ACOUSTICS BEFORE 1950

By the prominent milestones

- “On the sensations of tones” (1862) by von Helmholtz
- “Theory of Sound by Lord Rayleigh (1894/96)
- “Methods of Mathematical Physics” by Courant and Hilbert (1924)

the essential relationships of physical acoustics could be seen as known and well understood in early 20th century.

In parallel with the scientific exploration of acoustics, the end of the 19th century saw a rapid development of electro-acoustic technologies to transduce, register, transmit, reproduce and - finally - broadcast sound (newly introduced in Germany in 1923). Thus established, technical acoustics was the starting point for growing relevance and involvement of acoustic issues within the process of industrialization in the 20th century. At first, this development focused on providing and supporting desired sounds (electric sound recording, transmission, -reproduction and distribution). In addition to developing and extending worldwide broadcasting of sound signals via telephone and radio networks as well as tape and disc recordings, it was W.C. Sabine who was able to lay a solid foundation for targeted acoustic design and layout of auditory rooms to best adapt them to the perception of speech and music.

However, reduction of undesired sounds by technical means was increasingly recognized as an important discipline too, indispensable even for progressive mechanization of our world. Significantly interested circles thus were sure in the early 20th century already that noise abatement was a public duty, being claimed for instance by the first German noise abatement society founded in 1908.

Physical and technical acoustics tried to meet the respective requirements by successful research activities as well as by new findings and development results. Apart from com-

plementing and completing the far-sighted frameworks of Helmholtz and Rayleigh, this led to increasingly systematic investigations of sound generating, sound transmitting and sound controlling mechanisms. Exemplary examples were

- Berger’s mass law (1910)
- Derivation and validation of practical approximation formulas
- Introduction of “dB” (1920s)
- Introduction of loudness characterization in “phon” (1926)
- Derivation and experimental verification of coincidence effect by Cremer and Eisenberg (1942/48)
- Development and provision of versatile measurement technology
- Development and provision (by literature) of theoretically and empirically well-founded state-of-the-art reports for the most important disciplines of technical acoustics.

In total, in the middle of the last century, technical acoustics may be described as a discipline which felt committed to the fascination of new technical possibilities (electro acoustics) and quality-conscious hearing requirements (room acoustics) but also to the (still) weak social awareness of detrimental noise effects (noise control). By orienting successive insight along the requirements of increasing mechanization, acoustics had been able to recommend itself as an important instrument of prudential engineering activities: Technical acoustics was to become engineering acoustics.

At the time, one of the leading protagonists of technical acoustics was Lothar Cremer who - together with his teacher Erwin Meyer at the Technical University and Heinrich-Hertz-Institute in Berlin - had essentially contributed to state-of-the-art acoustics then. But the destructions of war had displaced both from Berlin: Erwin Meyer soon followed (1949) an appointment to the university of Göttingen and Lothar Cremer (also in 1949) started teaching at both, the Technical and the General (Ludwig Maximilian, LMU) University in Munich, where he later was appointed adjunct professor (1951-1953). Also, by license of the US occupation authority, Lothar Cremer had set up a small lab for acoustic research and consulting (“Akustisches Laboratorium”) in his private house in Munich. There, he followed up previous research work and - as reputable professor - private contracts for various acoustic consulting services.

By these two activities, Lothar Cremer set the basis for two institutions which both had a strong and lasting impact on the development of technical and engineering acoustics in the second half of 20th century: the Institute of Technical Acoustics (ITA) at TU Berlin ([3]) and the acoustic engineering consultancy Müller-BBM in Munich.

3. ACOUSTIC CONSULTANCIES OF LOTHAR CREMER AND HELMUT MÜLLER

3.1 Office Development

Among the successful attendees of his demanding lectures, Lothar Cremer discovered two attentive students with obvious talents, Helmut Müller and Manfred Heckl. He soon (1951) engaged them as student assistants in his lab to support him in measurements and calculations, evaluations and technical drawings.

Helmut Müller was born in 1929 in Neuburg an der Donau where he graduated from high school - together with his close school friend Manfred Heckl. During his school days, he was already pursuing his wide-ranging technical and physical interests which he put into practice with ambitious developments leading to useful, sometimes even successfully marketed results. Although he was temporarily interested in developing and manufacturing radio sets, he finally started - again together with his friend Manfred Heckl - studying physics at the Ludwig Maximilian University in Munich in 1949. His second main interest, music, took him and Manfred Heckl to the challenging acoustics course given by the private lecturer Lothar Cremer. He and his presentation held a strong fascination for both of them and attracted them permanently to this specialist field.

While working with Lothar Cremer in his lab, they started to follow different working preferences: Helmut Müller strongly involved himself in developing, testing and measuring solutions for the newly built concert hall “Herkulesaal” in the reconstructed Munich royal residence while Manfred Heckl focused on more theoretical and structure-borne sound problems. This difference of their topics was found in their diploma theses (1954) again, where Helmut Müller had put together his results of many detailed in-depth analyses for the acoustic design of Herkulesaal and Manfred Heckl had investigated sound bridges at floating floors.

After their diploma in physics, they went unplanned separate ways. Although Lothar Cremer had started successful consultancy business, he was ready to give up his office in 1954 and to follow his preferred research passion by accepting his appointment to become a full professor and director of the new Institute of Technical Acoustics in Berlin. He asked both his assistants to follow him to Berlin as doctoral research assistants, Manfred Heckl immediately and Helmut Müller a little later after closing down Cremer’s Munich business.

Helmut Müller failed in getting this done. The successful work of the lab created new and prominent business, the acoustical consultancy for the reconstruction of Munich’s

opera house (“Nationaltheater” and “Cuvilléstheater”) and for the construction of a new concert hall in Stuttgart (“Liederhalle”). Lothar Cremer and Helmut Müller both were sure that such prestigious projects by no means could be rejected and it turned out that this definitely paved the way for Helmut Müller’s life-long consultancy career.

Helmut Müller was a born consultant. By combining his in-depth physical understanding and curiosity with his experience, his remarkable ability to intuitively forefeel dependencies and solutions and his reliable sense for manageable risks, he was the right man on the right job. This was all the more true in that in cases of great uncertainty, he could simply consult his friend and his teacher, Manfred Heckl and Lothar Cremer.

Although sharing responsibility for the new projects, Lothar Cremer, as time went on, focused on his new duties in Berlin, thus leaving his Munich lab more and more on its own. Consequently, the lab soon was handed over to Helmut Müller who bought it from Lothar Cremer in 1958 and then renamed it “Schalltechnisches Beratungsbüro Helmut A. Müller”.

The growing number of orders soon forced Helmut Müller to rely on substantial support by qualified acousticians and engineers to be employed. This was the beginning of an extremely fruitful spin off period from ITA Berlin, providing proven skills and innovative know-how to the young consultancy. Lothar Cremer, who still gave substantial technical advice, recommended and arranged the employment of his best students and assistants in the Munich lab, the first being Achim Böhm in 1960.

However, the growth rate was limited by available capital and thus couldn’t follow the need given by the growing volume of orders. It was a nice coincidence then that at the International Congress on Acoustics (ICA) being held in Stuttgart in 1959, Lothar Cremer introduced Helmut Müller to Leo Beranek, a highly respected acoustician from Cambridge, USA. Leo Beranek, co-founder (in 1948) of the widely known engineering consultancy BBN (Bolt, Beranek and Newman), was impressed by the activities of the young Munich team and offered - by stating that “money is no problem” - financial participation of BBN. This idea was further explored when Manfred Heckl had a working stay with BBN in the US and finally led to the foundation of the “Schalltechnisches Beratungsbüro” Müller-BBN in 1962. The founding shareholders were Helmut Müller, Lothar Cremer, Manfred Heckl, Ludwig Schreiber (the latter two having obtained their doctorate degree at ITA recently) and BBN represented by Leo Beranek. The financial participation of BBN from the US was seen to be of mutual benefit, serving both companies to promote foreign business.



Figure 1. Notarial inaugural meeting of Müller-BBN GmbH (Sitting from left: 1. Lothar Cremer, 3. Leo Beranek, 4. Ludwig Schreiber, 5. Helmut Müller)

The shareholders appointed Helmut Müller to be managing director of the company and Leo Beranek to represent, as director, the shareholders' interest. By formally taking over the previous consultancy, the new company could be run in full continuity to its predecessor with respect to both, staff members and running projects.



Figure 2. Early staff of Müller-BBN (from left: H. Müller, M. Heckl, L. Schreiber, A. Böhm)

3.2 Projects and Technical Activities

Although born out of a distress (due to war and devastation) rather, the consultancy of highly regarded L. Cremer ideally met the needs of the time. Being one of the first private consulting offices which was able to apply engineering approaches to acoustic problems in due time and with full liability, it only needed successive proofs of competence to become widely known and to be frequently contracted.

The above-mentioned Herkulesaal project remained an ongoing challenge for Lothar Cremer and his young assistants in his Munich office. By imposing high demands on versatile usability (multi-purpose music hall allowing studio recordings) whilst maintaining strict shape and design requirements (flat audience area and wall hanging tapestry),

this hall required innovative solutions of best possible predictive accuracy.

Specific tasks to be accomplished were to,

- find a seating with pretty much the same absorptive effect as the one caused by the audience, to
- find methods of sufficient accuracy to predict the absorptive effect of huge tapestry, to
- find solutions how to supply distant audience areas with sufficient sound energy and to
- guarantee effective sound isolation against exterior noise to enable high quality studio recordings.

The first two problems could be solved by experimentally developing appropriate measurement procedures and using their result to specify design criteria whereas the third problem led to the worldwide first use of curved perspex reflectors above the stage. Because of other prescribed characteristics of the hall and its ceiling, this was necessary to direct enough sound energy to the rear seat area. Together with appropriate measures against exterior noise, the hall finally succeeded in being a long-term home for Bavarian Radio Symphony Orchestra and Deutsche Grammophon recordings. All measures taken are proven expertise today but needed novel ideas and approaches at the time.

Another example to illustrate the inventiveness required at that time is found by reviewing the measures taken in the late fifties for a thermal power station in the inner city of Munich (coincidentally in 'Müller'strasse'). It needed a large degree of courage and self-confidence to accept the condition that this power station should be inaudible, not increasing the existing background noise level. And it needed a lot of ingenuity to find ways how to meet this requirement.

Having quantified the requirement by long-term background noise measurements to 45 dB(A), Helmut Müller had to specify the noise sources (machinery) and the requirements for various constructions of the building to be able to make reliable predictions. All this was new ground: no standards, no databases, no guidelines, no concrete experiences. The first thing to do thus was to put great effort in a series of measurements in other plants to characterize the many machinery noise sources within the power station. Then practicable ways had to be found how to design and predict the attenuation of facade constructions and - finally - how to make sure that all transmission paths including vibration transmission had been considered. All this pioneering work was rewarded by the combined effect of all measures taken: the criterion to be inaudible, although hardly expected by neighbouring residents, was fulfilled and the well-targeted procedure to get there was acknowledged as a first, successful step towards the acceptance of industrial plants in residential areas.

4. MÜLLER-BBN - EARLY ACTIVITIES

4.1 Company Structure

In retrospect, Müller-BBN GmbH was a spin off of a scientific/technical elite of young, highly qualified and excellently trained acoustical engineers. By choosing the - at that time and for that business - unusual legal form of a limited liability company, the company was well prepared to make its employees personally liable shareholders. This model was (and still is today) consequently implemented by mechanisms to ensure that new shares could be provided for employees and to prevent that shares could be sold out of the company. Apart from the participation of BBN, the company should be owned by itself, by its employees.

The company grew rapidly, from 7 employees in the end of 1962 to 32 employees ten years later. It grew with its projects, its challenges, its experience and its success. And it made progress in finding an internal structure and governance which best fitted the self-responsibility and the motivation of its members.

Helmut Müller together with Manfred Heckl (who soon had returned to Germany again) and their early partners aimed at and succeeded in establishing an open, trusting cooperation of quasi self-employed, self-responsible colleagues. Apart from autonomous acquisition, processing and completion of orders, this cooperation and team spirit were promoted by flat hierarchies, fair offers of initial shares and open exchange of technical experiences and problems. As far as possible, the company was not only to be owned but also to be led by its mostly technical employees.

This unique staff member participation model was able to set the right frame for a long lasting and successful cooperation of many highly motivated colleagues. Due to high consensus in all relevant decisions, the model of so many fully influential co-owners worked for up to 200 shareholders even, and it took until 2009 that the model was converted into a stock company.

4.2 Technical Activities

While keeping continuity in its successful way of working, the improvement of its institutional and financial framework enabled the company to strictly improve its personnel and its spatial and instrumental resources. Due to growing demands for acoustical engineering services, the spectrum of technical competence grew along the application areas. The four talented students of Lothar Cremer, who were with the new company from its very beginning, soon felt forced to focus their professional activities around their specific interests but also around some particular topics being continuously addressed and contracted again and again. Thus, long

before formal thematic groups were introduced, a natural allocation of specialist knowledge and experience occurred. This will be shortly highlighted later in section 5.2

Increasing need for involving acoustic expertise grew out of social requirements. Having helped to fulfil basic sound requirements in the fast post-war reconstruction period, acoustics now was requested to ensure acceptable noise exposures within progressive mechanization and industrialization. Being the spirit of the time, this request was picked up by national and international initiatives of legal and professional organizations. In Germany, federal authorities and professional associations (like the commission for noise reduction, KLM, within VDI, the association of German engineers) had started to develop legal requirements and technical guidelines. Thus, technical acoustics was about to change its focus from improving desired sounds and sound environments to suppressing undesired sounds.

5. MÜLLER-BBM EXPANSION AND CONSOLIDATION

5.1 Company Structure and Infrastructure

In 1972, BBN asked the management of Müller-BBN whether the company could overcome the selling of their shares. At that time, the request from existing and potential (internal) shareholders was sufficiently strong and the takeover of the BBN shares was no problem at all, the more so as Leo Beranek also showed interest to personally take over some of the BBN shares. Of course, the leaving of BBN had to be linked to removing it from the name of the company. As by this time the name had become a distinguished trademark, a kind of brand already, the company was lucky to find a slightly different shortcut which nevertheless nearly sounds the same: Müller-BBM. Fortunately, this abbreviation also could be given a sense when interpreted as BeratungsBüro München (Consulting Office Munich).

The now called Müller-BBM went on to grow continuously in size, competence and business: from 32 employees end of 1972 to 211 end of 2000, 112 of them being shareholders.

It may be of interest perhaps that the physicists and engineers working with Müller-BBM soon represented all technical disciplines and that only some 50% of them were recruited as trained acousticians, the many others being recruited as particular specialists to best communicate and work with their trained engineering disciplines. They learned acoustics on the job and this best reflects the interdisciplinary nature of engineering acoustics which needs to understand the methods and processes, the thinking of the disciplines it works with and for.

By its very nature, interdisciplinarity best evolves from direct mutual communication and cooperation between the disciplines and their applications. Being identified as a useful source of mutual inspiration and competitive advantage, this internal communication was the reason for keeping the staff together at one company location. However, this location soon suffered space limitations in Munich and moved, in 1976, to new, expandable grounds and buildings in Planegg, close to Munich. And it took until the end of the century that the ease of electronic internal communication allowed to serve customers from closer geographic proximity by a wide-spread branch network.

5.2 Technical Activities

To illustrate the pioneering character of early engineering acoustics in the first post-war decades of 20th century, this section shortly reviews relevant developments together with some milestones of engineering acoustics and noise control engineering.

5.2.1 Architectural Acoustics and Building Solutions

The most urgent need after the end of war was to provide - as quickly as possible - habitable dwellings. It is clear - and it soon became obvious at that time - that this “quickly” had its price: insufficient acoustic comfort and acoustic annoyance by insufficient sound attenuation. In search of competent guidance how to find out of this dilemma, word got around quickly that the well-known acoustician Lothar Cremer might help - and that’s what he did. Having made a name for himself in structure-borne sound and sound radiation problems, he soon became a much-sought-after contact person for current acoustic and noise issues, and he was able to set trends for both, quick pragmatic advice and basic acoustic research.

This equally applied to room acoustics where Lothar Cremer soon could prove himself in small and in prestigious projects like the before mentioned Herkulessaal. By focusing himself on research later, he left his projects to his young assistant and successor Helmut Müller who first was hindered by Liederhalle in Stuttgart and the Munich opera house to follow his teacher to Berlin but then knew to use these opportunities for his business.

Thus, architectural acoustics was the kernel business for both aspects of early applied engineering acoustics: supporting and improving pleasant, enjoyable sounds as well as reducing and protecting from unpleasant, annoying sounds. Having successfully started and maintained this business, architectural acoustics became an important application area for the young consultancy - and a successful one! This can be seen best perhaps from some new approaches which had

been introduced first by Lothar Cremer and Helmut Müller to become frequently used standard approaches later.

- first freely suspended stage reflectors in concert halls (Herkulessaal)
- first consequent design of stepped audience blocks (vineyard steps, in Liederhalle Stuttgart)
- first movable ceiling above the orchestra (Staatstheater Karlsruhe)
- formulation and application of the first wavefront law
- consequent refinement of measurement methods to determine the absorptive behavior of materials and constructions.

Based on its achievements, acoustic concert hall design projects involving Müller-BBM soon spread out internationally. Today, the expertise of more than 70 years is substantiated in numerous, sometimes spectacular concert hall projects all over the world.

5.2.2 Industrial Noise control

Next to architectural acoustics, industrial noise control soon appeared to be another dominant driving force for further developing the toolbox of practical engineering acoustics. The rigorous acoustic treatment of the thermal power station in Müllerstrasse had shown that sound emission of large plants could be estimated by simple energy considerations which then allowed to meet achievable limit values. This was a key prerequisite for setting mandatory acoustic requirements for technical plants and installations because the predictable only can be planned. The resulting competitive lead gained by these unique experiences brought many follow-up orders and soon resulted in a market leadership: whenever and wherever a power plant was to be planned and built, Müller-BBM almost always was involved.

But there was another branch of industrial plants which needed completely different approaches of noise control: petrochemical plants, typically spread over large areas in open air due to risks of explosion. It was not possible therefore to build enclosures around the plant or parts of it. The predominant opinion of the time was that noise emitted by so many complicated sources and mechanisms was not predictable and control measures therefore only applicable in retrospect, after commissioning. It took many arguments and demonstrations to convince the operating companies that thorough determination of the sound power emitted by the great number of single aggregates would allow to predict the noise impact in the neighborhood. And it needed many basic investigations and measurements to provide all necessary data and influencing parameters.

In the early seventies, stringent but balanced control measures at all relevant sound sources (e.g. primary

measures at valves and fans) but also at appropriate sound transmission paths (e.g. secondary measures like encapsulation, blow-out or inline silencers) altogether were able to reduce the radiated sound power of petrochemical plants - in spite of increased plant performance - by some 15 dB(A). This means that the area exposed to a particular sound level could be reduced by more than 90% - an impressive demonstration of the potential of consequent noise control. Such pilot projects provided evidence that even large industrial installations could be operated in an environmentally compatible way in densely populated countries.



Figure 3. Balloon measurement of vertical radiation patterns within petrochemical plants (around 1970)

5.2.3 Vehicle Acoustics and Traffic Noise Control

The first vehicles being dealt with systematically at Müller-BBM were ships and it definitely was surprising to see that happen in Munich, far away from any sea. This may be traced back to previous contacts of Lothar Cremer, particularly to his early works for British Navy. In any case, being involved in the acoustics of ships forced the young consultancy to early investigations of structural dynamics and structure-borne sound which later helped to apply this progressive knowhow to other applications.

Looking back today, it seems strange that first acoustic analyses of seagoing vessels were done that far (1000 km) away from any German coast, but as said before, the team philosophy of Müller-BBM was to provide intensive exchange of ideas and experiences by keeping the team together in Munich - until new communication technology was introduced at least.

Among the many contributions to vehicle acoustics and traffic noise control, early pioneering work was applied to provide predictive estimates of traffic noise for roads and rails. As with the before-mentioned thermal power station, any tools for predictions such as in noise maps were not available, they still had to be developed. It took decades to complete, implement and provide, step by step, the large toolbox of clear standards, guidelines and extensive software packages we are used to have today.

An example of such an early step is shown in fig. 4 where a noise map has been calculated and drawn by hand from plausible estimates of sound propagation losses in a given landscape. Again, such calculations were the basis for clear and binding rules as fixed in relevant regulations, guidelines and software packages later.

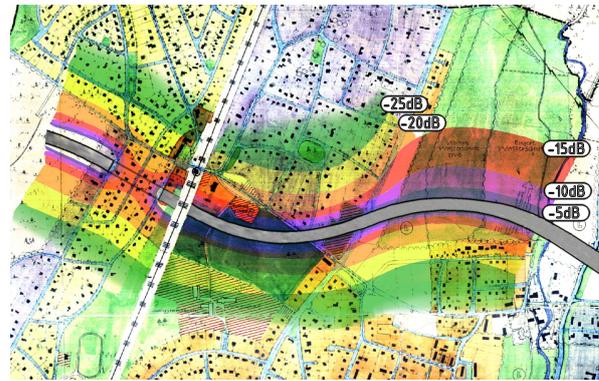


Figure 4. Early hand-drawn noise map (around 1970)

5.2.4 Other Technical Activities

Around its early core activities, architectural acoustics, industrial noise control, ship acoustics and traffic noise control, Müller-BBM from its very beginning was consulted to all technical areas where sound, noise and vibrations had to be considered - and these were all soon, indeed. Thus, the four first working areas and groups soon were complemented by new groups dealing with, among others, railway noise control, automotive acoustics, vibration engineering, structural dynamics, active noise and vibration control, acoustic product testing, software technology and computer-based measurement systems. Also, since the eighties of the last century, Müller-BBM followed growing demands of customers to complete its consulting services by adding new areas of expertise like thermal building physics or air pollution control.

In addition to applying state-of-the-art knowledge, all these activities needed state-of-the-art technology and equipment,

above all latest measuring instrumentation and computer technology. The wide span of using computers may be illustrated by two key points: the installation of the first private terminal in Germany providing time-sharing on-line access via modem to a mainframe computer in the US (in the 60s) and the development and application of high-end computer based multi-channel measurement systems (PAK) and signal-processor based active control algorithms since the 80s of last century.

In addition, it was only due to countless applications of computing power for measurement evaluations (like modal or correlation analysis) or numerical calculations and simulations (like FEM/BEM or SEA) that acoustical problems could be solved at all. But these and some other reviews (e.g. research and teaching activities or work in committees and associations) would definitely go beyond the scope of this paper.

6. OUTLOOK

Development and growth of Müller-BBM steadily continued after the early years described here. Today, Müller-BBM is a widely expanded engineering company with more than 1200 employees in many countries all over the world providing many services, also outside acoustics (see <https://www.mbbm.com/>). However, although the range of services and specialized products goes far beyond the here described spectrum of the early decades, the unique spirit of high acoustic core competence and self-responsible cooperation could be preserved and still contributes to motivation and commitment.

7. SUMMARY AND CONCLUSION

Fast reconstruction after World War II and upcoming comfort requirements from the following economic miracle rapidly increased the demand for technical acoustic know-how. Lacking any proven engineering tradition before, the involvement of technical acoustics relied on consulting services of specialized acoustic engineers who soon were able to establish themselves as a crucial interdisciplinary discipline. Then, growing comfort-of-life demands, together with increasingly urgent requirements of preservation of our environment, further forced acoustics and acousticians to control sounds. Thus, driven by social demands and driving for new results of scientific research and development, application-oriented engineering acoustics was closely bound into the iterative cycle which has made acoustics a relevant and exciting discipline again, thus essentially contributing to its renaissance in the second half of the 20th century.

Directly continuing and extending earliest post-war activities of Lothar Cremer, Müller-BBM had (and still has today) great formative influence on both, further developing and applying engineering acoustics and establishing it as an important interactive engineering discipline, typically provided by autonomous engineering consultancies. Although in many larger companies indispensable acoustic support today is provided by competent in-house groups with specialized knowledge and experience, the broad cross-application spectrum of acoustic engineering firms and their ongoing contributions to newest insight and technology seem to secure them a solid position in the interactive network of user- and environment-friendly engineering.

8. ACKNOWLEDGMENTS

The author gratefully acknowledges the documents and information provided by [1] and [2]. He also would like to express his gratitude to many former colleagues for remembering and contributing details from their personal perspective and experience.

Finally, the author highly appreciates the opportunity to express - by this review article - his admiration and gratitude for the work and guidance he received from the pioneering generation of Müller-BBM. They impressively taught him how to apply acoustic insight to the benefit of sustainable engineering solutions.

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ECHOES FROM THE ARCHIVES OF THE MUNICH SCHOOL OF PSYCHOACOUSTICS

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ABSTRACT

Eberhard Zwicker founded the Institute of Electroacoustics at the TH Munich, now Technical University of Munich, in 1967 and was joined by the psychoacousticians Ernst Terhardt and Hugo Fastl and, for speech recognition, by Guenther Ruske. The subsequent two+ decades were a highly fruitful period for psychoacoustics in Munich, leading to what can now be viewed as the “Munich School of Psychoacoustics”: Research on peripheral auditory processes led to key contributions to spectral and temporal auditory masking and to measures of critical bandwidth (BARK bands), while work on non-linear cochlear processes, including otoacoustic emissions, resulted in a non-linear electric model of the cochlea. Terhardt’s works on pitch, consonance and harmony were pioneering. Research on the percepts of sharpness, roughness and fluctuation strength laid the foundation for psychoacoustic sound quality. DIN 45631 and ISO 532b standardize Zwicker’s loudness model and bridge to a wide array of applications of psychoacoustics. While I am too young to have met Eberhard Zwicker in person, I have “inherited” his personal and the institute document archives and will report on selected research outcomes.

Keywords: *Munich School of Psychoacoustics; Eberhard Zwicker; Hugo Fastl; Ernst Terhardt; Masking; Pitch; Loudness.*

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1. INTRODUCTION

The Munich Three, Eberhard Zwicker, Ernst Terhardt and Hugo Fastl, were leading researchers in basic psychoacoustics who likewise contributed with their innovations to applied acoustics and industry. Rigorous technical developments formed the basis for research and led to countless devices for measuring various acoustic and perceptual quantities: research was conducted with stringently calibrated headphones with a free-field equalizer (Figure 1 and [1]), dedicated electronic devices were developed for measuring tuning curves and masking patterns (Figure 2), and a loudness meter was able to compute and display loudness of instationary sounds. This short paper cannot give an overview of the extensive research that took place in the decades at Zwicker’s Institute of Electroacoustics at the Technical University of Munich (TUM) – the research is excellently summarized in the book “Psychoacoustics – Facts and Models” [2-5]. What I am aiming at is to give pointers to a few aspects of their research that appear important to me and that impressed me as an electrical engineer who is nowadays mainly using commercial hardware and working with computers for stimulus generation and modeling.

2. AUDITORY PERIPHERAL PROCESSING AND MASKING

Understanding and modeling peripheral auditory processing was a key focus of Zwicker before coming to and then at TUM. He measured various conditions of masking: tones masking narrow-band-noise [6], tones masking tones [7], temporal masking [8], psychoacoustic tuning curves [9], masking in hearing impaired listeners [10] and later effects of binaural masking [11, 12]. Fastl also had an early research focus on temporal masking, the topic of his habilitation [13, 14].





Figure 1. Custom free-field equalizer for Beyerdynamic DT48 headphones [1].



Figure 2. Custom device for measuring psychoacoustic tuning curves.

Of particular interest were the non-linear effects of masking and how they relate to loudness perception. The level-dependent non-linear growth of masking and the asymmetry of masking below and above the masker were didactically worked out in Zwicker and Jaroszewski (1982) [7] and are replotted in Figure 3. The masking difference of 20 dB between the masking pattern and the mirrored masking pattern, highlighted with “A” in Figure 1, depicts the asymmetry toward increased masking at frequencies above the masker frequency compared to below – while “B” and “C” indicate the substantial non-linear increase (“upward spread of masking”) above the masker frequency with increasing masker level.

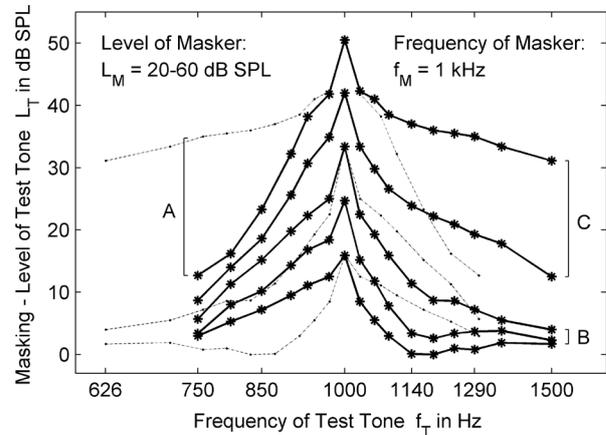


Figure 3. Tone-on-tone masking patterns are depicted with their mirrored version (on the Bark scale) to highlight the non-linearity of masking as measured by [7], replotted [c.f., 15].

Most masking effects can be understood and modeled assuming energy detection at the output of the auditory filter. This leads to the need of understanding filter bandwidth and shape. Zwicker derived the critical (filter) bandwidth measured in BARK from filter estimates obtained with several different approaches [4], amongst them the band-widening of noise when masking the probe tone, notched-noise masking and modulation-frequency dependent differences in the sensitivity to frequency and amplitude modulation. He defined the critical bandwidth in the unit BARK and an integrated critical band scale [16] which numbers the critical band filters from 1 to 24. For numerical modeling work, analytical, differentiable expressions were found for the BARK bandwidth and the critical band rate scale [17]. The critical bandwidth according to Zwicker is plotted in relation to other estimates of auditory filter bandwidth in Figure 4, as summarized in [15]. A simple estimate of the BARK bandwidth is: 100 Hz bandwidth for center frequencies up to 500 Hz and 20% of the center frequency for center frequencies above 500 Hz.

The extensive work about the auditory periphery led to a non-linear analog model of the cochlea, which was built in hardware (Figure 5). The model transmits energy between cochlear filters using a resistor network. In each cochlear filter, a phase-shifted feedback loop with non-linearity and with adjustable feedback attenuation simulates the amplification by outer hair cells (c.f. Fig. 3.9 in [4]). The

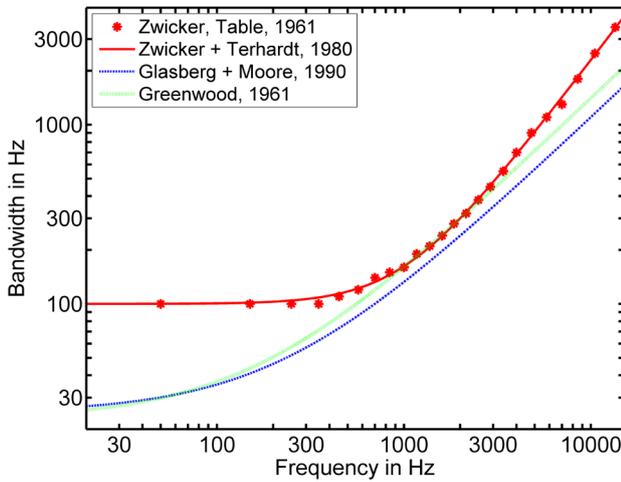


Figure 4. Measures of critical bandwidth: Zwicker’s tabular data (*, [16]) and formula [17] for BARK-bandwidth, the ERB-bandwidth by Glasberg and Moore [18], and the physiological bandwidth after Greenwood [19]. Replotted after [15].

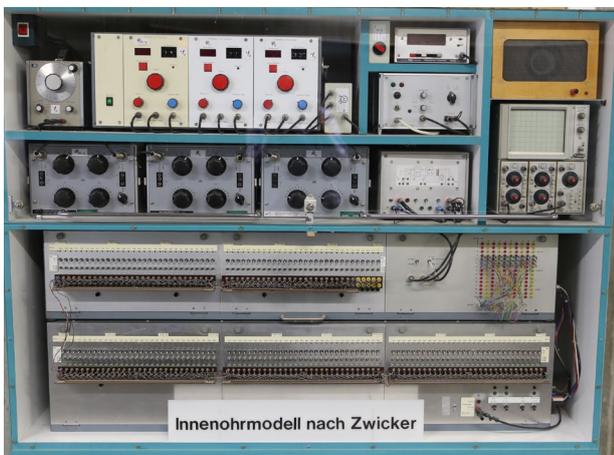


Figure 5. Hardware implementation of the non-linear inner ear model of Zwicker [3]. The filterbank (resolution 0.1 BARK) with non-linear feedback and connection across neighboring filters is visible at the bottom. On the top, two generators for tones with frequencies f_1 and f_2 are visible, and a third one with a phase shifter to generate a tone at $2f_1 - f_2$ to cancel the distortion product (“otoacoustic emission”) created by the non-linearity of the inner ear model. The output of each filter can be inspected on the oscilloscope and listened to.

distortion products were measured by phase-true cancellation [3]. The model was used for research on distortion products created by the inner ear and otoacoustic emissions.

3. LOUDNESS

Given Zwicker’s extensive knowledge about masking and the auditory periphery, the loudness of sounds was of paramount interest. Several studies investigated how loudness develops above masked threshold and integrates across critical bands [20], leading to the loudness model by Zwicker, which is based on collaborative work with Stevens and Scharf [20-22]. The model was developed into the ISO 532B standard [23] and later extended for dynamic sounds [24] and for hearing impairment [25]. While the early standard used a paper chart to compute loudness, digital hardware implementations were soon available for use in technical acoustics settings.

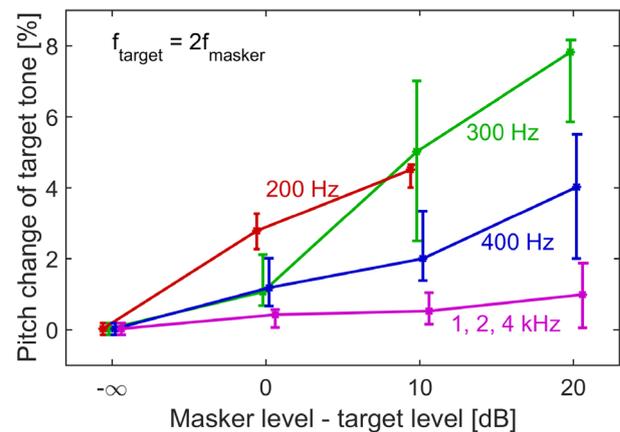


Figure 6. Pitch shift of a target tone twice in frequency of the masker tone, as a function of its relative level to the masker. Pitch shifts up by up to 8% for partially masked tones. Replotted after [26].

4. PITCH, CONSONANCE AND HARMONY

Ernst Terhardt’s focus was on pitch perception and music. In psychoacoustic experiments, he measured pitch shifts to find the effects of level and partial masking by other spectral components. For example, the pitch of a spectral component can shift up (or down) by several percent if it is partially masked (Figure 6, [26]). These masking effects also extend to harmonic complexes and agree with the pitch being derived from a spectral, place pitch mechanism.

Based on his findings, he developed a model of virtual pitch based on subharmonic coincidence matching, which predicts various virtual pitch phenomena, including pitch ambiguities and changes in virtual pitch due to masking and component level [26, 27]. His insights are summarized in the book “Akustische Kommunikation” [28].

5. TEMPORAL PROCESSING AND SOUND QUALITY

Hugo Fastl likewise worked on basic psychoacoustics, with a focus on temporal processing [13, 14, 25], but he is also known for translating psychoacoustic knowledge to technical acoustics. He advocated the use of psychoacoustic quantities in the sound design process [29] and worked on composite sound quality measures, e.g. psychoacoustic annoyance/pleasantness derived from factors of loudness, sharpness, roughness and fluctuation strength. Several studies at the institute investigated roughness, which was found to follow a bandpass-characteristic irrespective of level and masking: roughness increases from low modulation rates to peak at around 70 Hz modulation rate, to decrease thereafter at higher modulation rates [30], see Figure 7.

His interest in temporal processing is also visible in his suggestion for a fluctuating noise for speech audiometry, now known as “Fastl-noise” [31]. Speech intelligibility strongly depends on our ability to listen into temporal gaps in a temporally modulated noise masker, like speech. He suggested a noise that not only has the long-term spectrum of speech but also shares the modulation spectrum with speech. Since it is noise, it will not contain any meaning and thus not cause “informational” masking.

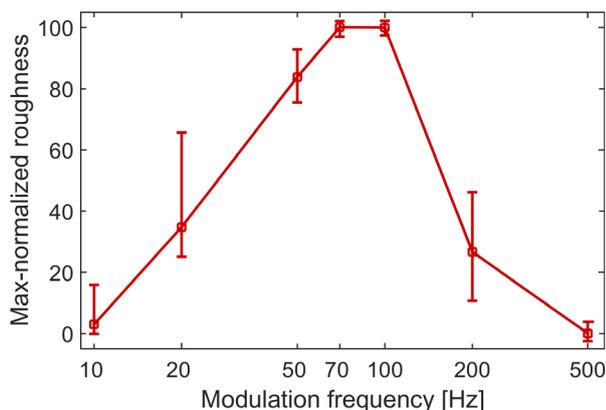


Figure 7. The roughness of amplitude modulated tones. Replotted after [30].



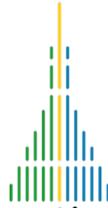
Figure 8. Zwicker Institute publication archive containing pre-prints and background material on almost 800 publications of the institute.

6. ANNOTES

As hinted at in the introduction, the research approach at Zwicker’s institute was of thorough engineering: custom devices were built when necessary and deep understanding of electrical engineering and acoustics was assumed. The organization was thorough as well and is still leading in today’s times of open science data management: the publication archive contains background material to almost 800 publications, including pre-prints, data, notes and figure drawings (Figure 8).

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60 YEARS' ACOUSTICS AT RWTH AACHEN UNIVERSITY

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ABSTRACT

The Institute of Technical Acoustics, ITA, was founded at RWTH Aachen University in 1963. First leaders were Wilhelm Janovsky and Heinrich Kuttruff. Today, institute directors are Michael Vorländer (since 1996) and Janina Fels (since 2012). In 2021, the Institute was renamed "Institute for Hearing Technology and Acoustics - IHTA", due to its increased involvement in interdisciplinary networks at RWTH Aachen University, with an increased focus on hearing research. Since 1963, generations of students in electrical engineering and information technology were educated in graduate courses, as well as physicists and mechanical engineers. The increased activities are also reflected in a broader range of teaching modules and laboratory equipment. From 2025 on, the institute will continue with an additional emphasis in hearing technology but without losing the broad coverage of technical acoustics and acoustic virtual reality.

Keywords: *history, acoustics, university*

1. INTRODUCTION

In 1963, the Institute of Technical Acoustics, ITA, was founded at RWTH Aachen University. The focus in the first decades was acoustics in its very wide range of fundamentals and applications covering musical acoustics, room acoustics, ultrasound, psychoacoustics, noise control, and signal processing for measurement and sound analysis. The leadership included Wilhelm Janovsky (1963-1971, figure 1), Heinrich Kuttruff (1972-1995), Michael

Vorländer (1996 -) and Janina Fels (2012 -). In 2021, the Institute was renamed "Institute for Hearing Technology and Acoustics - IHTA", due to its increased involvement in interdisciplinary networks at RWTH Aachen University, with a stronger focus on hearing research. Since 1963, generations of students in electrical engineering and information technology, as well as physicists and mechanical engineers, have been trained in graduate courses. The paper summarizes some historical facts of the academic contributions. Names and dates were mostly taken from [1].

2. EARLY YEARS - 1963-1972



Figure 1. Wilhelm Janovsky teaching electroacoustics in the "FT" auditorium (picture taken by Franz Buchholz).

2.1 Acoustics in communication engineering

Since the 1950s, the Institute for Communications Engineering (IENT), (headed by Volker Aschoff, later Rector of the RWTH) offered lectures on electroacoustics. Aschoff was the teacher of Jens Blauert, who is one of the founders of all we know about binaural hearing. Aschoff was followed by Hans Dieter Lüke who continued the work of the IENT group on psychoacoustics and binaural hearing

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until the 1990s. Klaus Genuit and Hans-Wilhelm Gierlich, the driving forces behind HEAD acoustics, graduated from the IENT.

2.2 Acoustics becomes independent

During Aschoff's time, and even before that, Wilhelm Janovsky was involved as expert and docent in various field of acoustics. Finally he was offered a full professor's position in 1961 and head of the Institute of Technical Acoustics – ITA, in 1963/64. Wilhelm Janovsky supervised 6 PhDs in 1963-1970. His main research areas were sound and vibration in general, and psychoacoustics. He also co-supervised 16 PhDs, most at mechanical engineering. Also in 1963, the „Ultrasound Laboratories“ led by Reimar Pohlman were associated with the ITA. Pohlman was leading the “Ultrasound labs” in Aachen between 1957 and 1977. He was teacher of Joachim Herbertz, who was later professor in Duisburg and actively involved in health effects caused by high frequency airborne sound.

3. ITA RWTH 1972-1996

The decades of the 70's, 80's and 90's were marked by Heinrich Kuttruff. With him, a very strong focus was set on room acoustics and ultrasound, but not reducing the fundamentals in the education program and in research. Kuttruff's research and teaching was strongly influenced by his career background from the 3rd Institute of Physics of Göttingen University and his mentor Erwin Meyer [2]. After doctorate in room acoustics and habilitation in ultrasound (cavitation and sonoluminescence), he taught as a docent in Göttingen and was appointed professor first at the Technical University of Darmstadt and professor and director of ITA in Aachen in 1972.

Starting with 1972, acoustics at RWTH got a significant change in terms of increased laboratory, workshop and office space in a new building (figure 2). After structural restrictions and interim solutions, this was the starting signal for expanded research and teaching activities.

Heinrich Kuttruff taught “Technical Acoustics” (part I and II), “Ultrasound”, and “Room acoustics”. The Technical acoustics laboratory of 11 student experiments completed the teaching portfolio, of course also including thesis projects for students finishing a diploma degree (5 years) in electrical engineering or in physics. The class size in the fundamental lectures was about 100, in the special lectures around 20, the number of students who worked on their final thesis was about 10 per year (thus being considered as “acousticians”). This is to be correlated with typically 800 beginners in the electrical engineering diploma course.



Figure 2. New ITA building, Neustr. 50, in Aachen-Burtscheid (picture taken by Franz Buchholz).

The research topics were quite diverse and span from nonlinear bubble dynamics, room acoustics, quality of violins, noise propagation in urban areas, multi-channel electroacoustics, speech enhancement.

The main achievements from that time were an alternative approach for artificial head design, based on the best-matching individual who “donated” his individual shape as basis for the ITA dummy head. The best match was determined in inter-subject listening experiments with a dataset of individual HRTF. Another significant achievement was the early version of room acoustic ray tracing software and its continuous maintenance (until today) on the one hand, and DSP hardware and software for control and measurement of electroacoustic and acoustic systems on the other.

4. ITA RWTH AFTER 1996

After Heinrich Kuttruff retired, Michael Vorländer was appointed his successor in 1996. Coming from the Physikalische Bundesanstalt (PTB) in Braunschweig, he included more elements of measurement, calibration and digital measurement technology in the lecture series, but kept the basics of Kuttruff's "Technical Acoustics". The ultrasound laboratory was closed due to high maintenance costs and lack of space.

The tradition of sustaining the software tools and the infrastructure over a long time was kept on purpose. This way, the simulation software emerging from the 1980s could be used a basis for continuous extension and improvement. Also, the DSP technology framework was maintained.

In 2012, Janina Fels joined as an assistant professor. She set up her own group with a focus on hearing technology and expanded its activities over the years. In 2020, she was appointed Full Professor for Hearing Technology and Acoustics.

4.1 Teaching: Continuity with slight adaptations

With the scientific and the technological progress after 2000, computer simulation became more emphasis. This was also expressed by a new lecture on “Acoustic Virtual Reality”. “Psychoacoustics” was taught by Klaus Genuit who was invited to join the teaching activities as adjunct lecturer (later adjunct professor). “Measurement techniques and electroacoustics” (taught by Gottfried Behler) and Medical Acoustics (part I: Technologies for Hearing Systems and Ultrasound, part II: Audiology and Voice, taught by Janina Fels) were added in 2009, also “Psychoacoustics and Methods for Listening Experiments, in 2016”. “Room acoustics” was transferred into an intensive course format (1 week full-time) with added content of sound reinforcement systems and supported by external lecturers (Alfred Schmitz, Anselm Goertz).

In 2020, teaching was further extended towards more offers for students of architecture (Josep Llorca-Bofi).

The class size in the fundamental lectures today is about 200, in the special lectures around 40, the number of students who worked on their final thesis was about 20 per year (thus being “acousticians”). This is to be correlated with typically 350 beginners in the Bachelor’s course of electrical engineering and information technology.

4.2 Research: Extension towards hearing technology

With two full professorships, more diversity is covered, and more infrastructure is required. In research, acoustic virtual reality and binaural hearing technology became the core of research but still in a very wide setting of research questions and applications. This is also reflected in the integration of research consortia (and teaching) in interdisciplinary teams at RWTH Aachen University which combined acoustics with architecture, electrical engineering, mechanical engineering, biology, psychology, and computer science.

In particular, hearing technology group grew over short time, so that the institute’s name was changed from ITA (technical acoustics) to IHTA (hearing technology and acoustics). Funds for large research consortia such as the priority program AUDICTIVE were acquired by Janina Fels, linking the disciplines of hearing science with virtual reality and cognitive psychology. This is a proof that acoustics can play a big role in an interdisciplinary context of sound, perception, and design.

Also, between 2021 and 2026, a third group in IHTA, named “PAAD” (Person-focused Analysis of Architectural Design) led by the Junior Principal Investigator (equivalent to assistant professor) Josep Llorca-Bofi.

5. CONCLUSION AND OUTLOOK

Acoustics at RWTH Aachen University was established by ITA, now IHTA, since 60 years. The growth in terms of capacity and impact in research and teaching started around 2010, with more emphasis on hearing research and with a second professorship. Teaching was supported by external docents. And this was well accepted by the students who, in relation to registration of first-years students, came to study acoustics in much larger numbers than in the 1960s and the 1990s. This may be an indication of the increased relevance of acoustics in many more branches of engineering. Digital technology as well for measurements as for computation paved the way for breakthroughs in system identification and simulation. With the most recent appointments, the branch of hearing technology is added to IHTA’s activities but, most important, without losing the technical part of measurement and simulation of acoustic systems in general. From today’s perspective, acoustics at RWTH Aachen University has a promising future in its interdisciplinary integrated structure.

Up-to-date information about IHTA can be found on the Website [3].

6. ACKNOWLEDGMENTS

The authors are grateful for personal information and a photograph archive of Franz Buchholz, the head of the electronic workshop at ITA between 1963 and 2000.

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DEVELOPMENT OF ACOUSTICS AT THE NEW UNIVERSITY OF OLDENBURG

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ABSTRACT

In the 70s, new universities were founded in Germany, including in Oldenburg (1974). In order to prepare for teaching and research, planners from traditional universities had to support these new universities. Oldenburg received support from scientists from the renowned "Drittes Physikalisches Institut" (Göttingen), which covered subjects from room acoustics to high-frequency ultrasound, and in 1975, Volker Mellert moved from Göttingen to a professorship in Oldenburg. One goal of the new university was practical training and research for the well-being of the people. Together with the planner Ulrich Radek, a unit "Acoustics" was founded within the Physics Department. This newly founded Acoustics Group started research on environmental noise, in particular industrial and traffic noise. Measurements were carried out with students on real objects outdoors and evaluated in the laboratory. Many years of research into outdoor wave propagation, and the perception of sound followed. Research in the broader field of acoustics was significantly expanded with the appointment of Birger Kollmeier (1992), and the Acoustics Group participated in Collaborative Research Centres and a Cluster of Excellence (2018) on Hearing Research. The Acoustics Group became part of the new "Department of Medical Physics and Acoustics", now headed by Steven van de Par since 2010.

Keywords: *Oldenburg, acoustics, sound propagation outdoors, hearing research, psychoacoustics.*

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1. INTRODUCTION

At the beginning of the 1970s, there were a number of new universities planned in Germany. In Lower Saxony, universities were founded in Oldenburg, Osnabrück and Lüneburg with the aim of enlarging the educational offer in the area. Traditionally, in Lower Saxony there was only one general university in Göttingen, and technical universities in Braunschweig, Clausthal and Hannover, whose range of subjects was later expanded. To prepare for the start-up, scientists were sought who, as planners, would prepare both the appointment of the first professorships and the subject-related infrastructure. Staffs were often recruited from established universities of the Federal State, respectively. From the renowned "Drittes Physikalisches Institut" of the University of Göttingen (M.R. Schroeder), came to planning the subject physics Dr. F. Bader (laser physics, applied optics) and Dr. U. Radek (ultrasound, cavitation) and to establish the university computer centre Dr. B. Wagener. Implicitly a slight tendency for applied physics and signal processing was predestined. An orientation on laser physics and spectroscopy was achieved through the appointments of Dr. J. Luther (Hannover) and Dr. K. Maier (Regensburg) for the first professorships in experimental physics. Later, the internationally renowned focus of the university in "renewable energy" was promoted by the work of Prof. Luther.

2. STUDY PROGRAM

When the university was founded in 1974, a so-called "project-oriented" study program was planned that takes up practical problems as early as possible in the training and uses them to convey the professional basics. Related to the fact that at this time some younger scientists became aware of the "Limits to Growth" (Club of Rome, 1972), planning in Oldenburg showed a certain orientation towards

“environment” and “sustainability”. University education, research and development should help solve problems that people experience in an environment that is becoming increasingly less livable. "Acoustics" was identified in the physics planning as an appropriate approach to practical training. Volker Mellert moved from Göttingen to Oldenburg in response to a corresponding professorship vacancy. In the 1974/75 winter term, he planned a so-called project with U. Radek on the subject of "Noise". The content of the "scientific" part of "Noise" must be announced for the students of the summer term - the formal information read (original quote translated):

- Experimental study of the effects of noise on humans
- Development of easy-to-use measurement methods for noise assessment
- Signal analysis using electronic data processing systems
- Generalization of the mathematical signal description in application to other physical phenomena

A first outcome of the “Noise” project was the "Comparative assessment of traffic noise" [1] (in German).

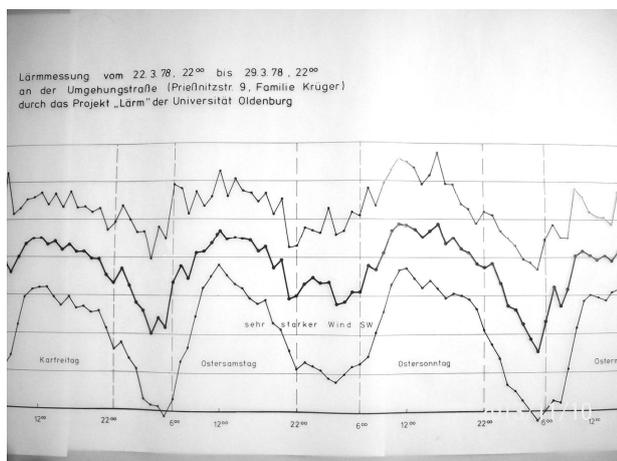


Figure 1. Section of a long-term traffic noise measurement in the shade of a noise barrier. Ordinate starting at 40 dB(A) in 5 dB steps. „Strong wind“ at night enhanced the immission by about 5 dB. (Student working group 1978).

One requirement of the project-oriented training was leaving the laboratory in order to carry out relevant investigations outside in the environment. A current project that time was the construction of a bypass autobahn in Oldenburg (including noise barriers) in the 1970s. It made sense to carry out long-term measurements of the

immission at a house near the motorway with a student working group, and to analyze the level reduction by the noise barrier (Fig. 1). Incidentally, a citizens' initiative "against noise" was supported by our measurements which led to fierce political disputes in the local newspaper, and provided the students with certain insights into social contexts. (The “project-oriented” study program should include social-related aspects.)

Physically, the course of the level values showed the clear dependency of the sound propagation on the weather conditions. In the years that followed, many studies of sound propagation outdoors were carried out in the Acoustics Group, e.g. development of a powerful impulse sound source and measurement of sound propagation outdoors, modelling noise propagation from high-lying sources, measurements of ground impedance, sound scattering through turbulence [2-4].

3. SOUND PROPAGATION OUTDOORS

In 1975, the university divided the growing natural sciences into the classical subjects of Biology, Chemistry, Mathematics and Physics. In physics, the working groups "Theory", "Laser Physics", "Spectroscopy", "Optics", "Didactics" and "Acoustics" were first defined, from which various departments later emerged. The first PhD student of the new Acoustics Group was W. Wilken, who experimentally investigated the fluctuating sound propagation in the atmosphere near the ground [5, 6]. The phenomena observed outdoors were studied in parallel in a model system in the laboratory by means of ultrasonic propagation through a thermal "phase screen" of fluctuating air [7].

One problem of the new university was the lack of suitable laboratory space. For investigations in acoustics, a room with highly absorbing walls was missing. A real anechoic chamber could only be realized with the move into the new buildings of the natural sciences in 1982. Before that, however, it was possible to raise funds for a small acoustic measurement room (lower cut-off frequency 125 Hz), which could then be erected in a separate building (Fig. 2). The new big anechoic chamber (Figs. 3 & 4) was 1982 built within the physics department, mounted on springs for vibrational damping, and with a true 50 Hz cut-off frequency¹. The background noise lies well below the threshold of normal hearing, which allowed for a re-determination of the threshold in an international cooperation [8].

¹ Currently (2022), the large anechoic chamber has been renovated and provided with new absorption material and low-emission ventilation.



Figure 2. Small anechoic chamber of the Acoustic Group (about 1980) with R. Weber, W. Wilken, V. Mellert, U. Radek.

In addition to measurements of subjective acoustic perception, the size of the room also allows the measurement of the sound radiation of a source under free-field conditions. U. Radek developed a powerful electrical spark source for determining the acoustic transfer function of sound propagation outdoors under given "frozen" atmospheric conditions [9, 10]. The spark source provided a highly reproducible δ -impulse (Fig. 3). The optimization of the sound source could not be completed. U. Radek died in 1991 after a short, serious illness.



Figure 3. Acoustic δ -impulse spark source attached to a horn speaker.

The experimental studies on outdoor sound propagation were substantially supported by the dissertation projects in

theoretical physics of Baowen Li² and R. Große³ [11, 12], and the intense theoretical research of wave propagation in turbulence by the visiting scientist V. E. Ostashev⁴ [13-15]. In addition, the problem can be inverted (cf. tomography): The acoustic measurement allows conclusions to be drawn about the profile of the speed of sound or the wind and temperature distribution as well as the structural parameters of the atmosphere [25-30].

4. IMPEDANCE

Another important parameter that influences sound propagation is the impedance of the boundary, in this case outdoors that of the ground. The wave propagation is strongly influenced by the (complex) ground impedance at grazing incidence. In the Acoustics Group, ground impedance was investigated in many research projects by measurements outdoors and theoretically for the effective modelling of sound propagation as well as for determining properties of acoustic material [16-24]. In the general case of grazing wave propagation along a boundary with the constraint of finite impedance, the wave can be described by a guided "ground wave", which leads to significant destructive interference with the free wave. The sensitive dependence of this interference on the nature of the interface opens up interesting measurement methods for material properties [31]. Depending on the geometric arrangement of transmitter and receiver, the first minimum of the ground wave interference changes in the (experimentally measured) transfer function. With this finding, we have proposed an acoustic underwater measurement method for the detection of drowned, fluid pollutants, since fluid pollutants deposited on the sediment are often not optically (i.e. spectroscopically) identifiable [32-34]. The measurement method was successfully tested in situ in a river, but not continued after the end of the project funding. The "excursion" of the Acoustics Group underwater led, among tackling other problems in technical acoustics, to the founding of the spin-off itap GmbH, which has since developed into a renowned measuring and consulting center for underwater sound, e.g. in monitoring the emission of marine structures⁵. The "Noise" project led not only to broad investigations of wave propagation but

²Now: <https://faculty.sustech.edu.cn/?p=170792&tagid=libw&cat=2&isess=1&snapid=1&orderby=date&go=1&lang=en>

³ Now: R. Wandelt, Jade Univ. Applied Science <https://www.jade-hs.de/unsere-hochschule/fachbereiche/seefahrt-und-logistik/team/professor-innen/>

⁴ Now: University of Colorado Boulder: <https://www.researchgate.net/profile/Vladimir-Ostashev/2>

⁵ itap GmbH, <https://www.itap.de/en/>

also to numerous questions concerning the subjective perception of sound and vibration.

5. PERCEPTION OF SOUND AND VIBRATION

5.1 Graduate School Psychoacoustics

V. Mellert's experiences from Göttingen with subjective sound field recordings in head-related stereophony [35] for the investigation of concert hall acoustics initially led to an optimization of the manikin head microphone device in Oldenburg [36] to be used for the recording of environmental and industrial sound (or subjectively: noise) [37]. Fortunately, at the beginning of the new university in 1974, August Schick⁶ was appointed to a professorship in psychology. Prof. Schick was interested in the perception of the environment by humans; he later founded the "Institute for the Study of Human-Environment Relationships". In 1975/76, soon after starting the "Noise" project in physics, A. Schick announced the seminar "Loudness and noise from a general and differential psychological point of view"(in German)⁷, to which our physics students were sent. This was the beginning of a fruitful collaboration in acoustics between the subjects of physics and psychology. A. Schick built up an extraordinarily extensive literature database on psychological acoustics and organized ten international "Oldenburg Symposia on Psychological Acoustics" from 1978 to 2008, the results of which are documented and available in several 1000 pages⁸. During the symposia, the plan to establish a "Graduate School Psychoacoustics" with the claim "Auditory Signal Processing, Sound Evaluation and Sound Effect – Modelling of Basic Auditory Properties for Technical Applications and Clinical Use" was developed. The School started 1992, and has been extensively funded by the German Research Foundation DFG for 10 years. Significant personnel support in the application for the Graduate School Psychoacoustics was provided by the appointment of Dr. rer.nat, Dr. med. Birger Kollmeier, who had already established a strong working group on "Hearing Acoustics" at the "Drittes Physikalisches Institut" in Göttingen. Prof. Kollmeier succeeded in "relocating" his research group to the University of Oldenburg. Thus, the competence in acoustics in Oldenburg was not only doubled abruptly, but also expanded to include the medical aspect of hearing. The physics of hearing with the transmission of sound from the outer ear to the

transformation into the neuronal representation of what is heard became a focus of "Medical Physics and Acoustics"⁹ under the direction of B. Kollmeier. In 1996 he founded the "House of Hearing"¹⁰, which became an important research and development center for hearing-related diagnostics.

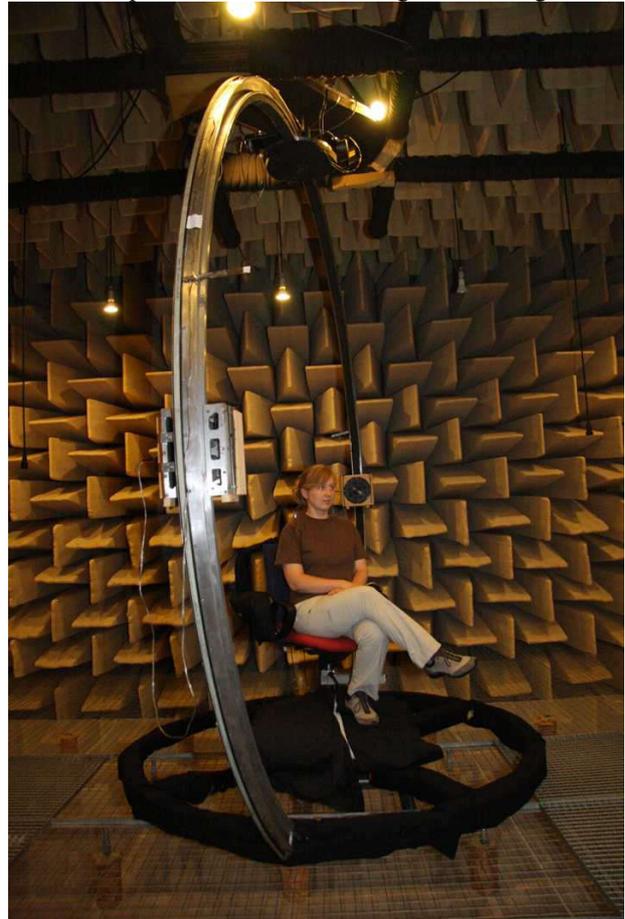


Figure 4. Investigation in directional hearing with moving speakers on rails in the large anechoic chamber.

The Graduate School Psychoacoustics can be considered one of the roots for later Faculty of Medicine at the university. In 1996, the scientists of the Graduate School, together with other colleagues from Biology and Psychology from Oldenburg and from the neighboring University of Bremen, founded the Collaborative Research Center 517 "Neurocognition" (until 2005), which became the essential basis for the establishment of the Faculty of

⁶ https://de.wikipedia.org/wiki/August_Schick

⁷ Lautheit und Lärm aus allg. u. Diff.-psychol. Sicht

⁸ <https://uol.de/psychologie/emeriti/august-schick#ospa> (section „Publikationen“)

⁹ <https://uol.de/en/mediphysics-acoustics>

¹⁰ <https://www.hz-ol.de/en/house-of-hearing.html>

Medicine in Oldenburg. Research in the Graduate School led to many doctoral theses; the results have been presented at international congresses and published in scientific journals, e.g. [38-40]. All graduates and publications are listed in Prof. Schick's aforementioned database. A further report on the Graduate School Psychoacoustics exceeds the given number of pages.

5.2 Applied Psychoacoustics

In addition to research in sound propagation, directional hearing and psychoacoustic parameters in connection with subjective loudness, technical sounds and vibrations were investigated in the Acoustics Group in order to characterize their subjective perception by suitable parameters and making them measurable with the help of a functional model, e.g. [41,42]. It is of particular interest to quantify how the perception of sound and vibrations contributes to the reduction of comfort at work, during travel or generally to the annoyance in the respective individual environment [43-45]. A significant disturbance in comfort is caused by structural vibrations. For the quantitative measurement of the frequency-dependent perception of whole-body vibrations, a special vibration laboratory with vibration shakers and sensors was set up in the Acoustics Group. Michael Bellmann investigated the fundamentals of vibration perception in his dissertation thesis [52].

Travel comfort is an important factor in competition, e.g. in air travel. This aspect was investigated in several large European projects in which the Acoustics Group was involved. Vibro-acoustics were a major issue in IDEA PACI [57,58], HEACE¹¹[46-51], and in FRIENDCOPTER with psychoacoustic questionnaires [59,60]. We provided in ICE and FACE appropriate vibro-acoustic environment [61-63] and analyzed passengers' perception of comfort.

In the production of mechanical systems and especially in motor vehicles, the acoustic information content in the radiated sound is subjectively often used as a "condition monitoring". Therefore, reproducible measurement procedures are useful for objectifying the auditory sensation [53-55]. Especially (variable) tonal components in predominantly broadband noise are focused in acoustic perception and have either an informative or annoying character. Technical measurement methods for "tonality" were investigated and expanded in Matthias Vormann's dissertation thesis [56].

¹¹ The Acoustic Group was project leader

5.3 Medical Physics and Acoustics

The physics and physiology of hearing are of great importance for the development of medical and technical aids for hearing-impaired people. On the other hand, research into the physiological causes of hearing loss provides deeper insights into neuronal signal processing. Compensating for the loss of hearing requires not only the involvement of medicine, but also the development of complex signal processing in appropriate electronic aids. Soon after 2000, the thematic breadth necessary for research into the sensory organ led to cooperation with the Hannover Medical School and the University of Hannover as well as to the establishment of the "Hearing Technology and Audiology"¹² course, including joint doctorates at the Jade University of Applied Sciences Oldenburg (Prof. Matthias Blau¹³). In 2012, Prof. Kollmeier and his Medical Physics Group, together with scientists from Biology, Psychology, Medicine and Technology, successfully acquired the Cluster of Excellence "Hearing for All"¹⁴. A "Department Medical Physics and Acoustics"¹⁵ was formed 2013 in the new School of Medicine and Health Science with the previous acoustic groups. The Department was expanded by eight research sections with corresponding professorships, laboratories and research facilities. Since 2010, the research of the Acoustics Group has been continued in the "Section Acoustics" with great success by Prof. Steven van de Par, after Prof. Mellert retired in 2009.

6. ACKNOWLEDGMENTS

With the construction of the science faculty buildings of the new University of Oldenburg in 1982, the Acoustics Group was able to move into laboratories with solid basic equipment, including a large anechoic chamber and an acoustic wind tunnel. However, the university's personnel resources were and are (traditionally) very limited. It was and is therefore necessary to raise project-related research funds in order to enable students to gain professional qualifications by working in a research and development project. Without the support of the German Research Foundation DFG, the European Commission and the Federal and State Ministries, each of which is responsible for the subject, the contribution of the Acoustics Group to the subject acoustics would not have been possible. We would like to take this opportunity to thank the institutions for funding.

¹² <https://www.jade-hs.de/tgm/studium/ha/>

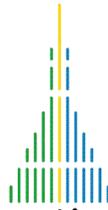
¹³ <https://www.jade-hs.de/team/matthias-blau/>

¹⁴ <https://uol.de/exzellenzinitiative>

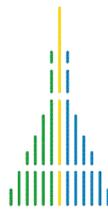
¹⁵ <https://uol.de/en/mediphysics-acoustics>

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HOW BINAURAL MEASUREMENT TECHNOLOGY AND PSYCHOACOUSTICS HAVE CHANGED ACOUSTIC MEASUREMENT TECHNOLOGY

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ABSTRACT

In the 80s of the last century, the automotive industry developed an interest not only to measure the interior noise level of a vehicle, but also to determine the acoustic sound quality. The annoyance of a noise or the attributes of good sound could not be described by the A-weighted sound pressure level. The desire arose to include human hearing into the analysis. However, artificial head stereophony, which was used in the broadcasting sector, proved to be unsuitable for enabling a faithful reproduction of vehicle interior noise. An improved, calibratable and free-field equalized artificial head measurement technology was developed with technical properties comparable to human hearing combined with headphone playback to generate same hearing events as in the original. Furthermore, based on digital signal processing, possibilities were created to change signals in the time and frequency domain in real time to audibly assess which signal characteristics influence the sound quality. With the help of psychoacoustics, calculation methods could quantitatively describe the sound impressions perceived by hearing. Meanwhile, the ISO 12913 Soundscape standard defines the recording and assessment of an acoustic environment in context, whereby binaural measurement technology is normatively requested, and the use of psychoacoustic parameters is recommended.

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1. INTRODUCTION

At the beginning of the 80s, the acoustics engineers at a large German automobile manufacturer recognized the problem that noises were perceived differently, but they could not be analyzed and quantitatively measured in a differentiated way. This gave rise to the idea of including human hearing in the analysis process. This means that the sound situation should be recorded and reproduced true to the original. However, the artificial head systems available at the time were not qualitatively able to guarantee a faithful reproduction of ear signals.

2. BINAURAL RECORDING

The human hearing has two input channels that enable binaural signal processing to recognize the direction of sound sources, to select single sound source among several different sources (selectivity), and to suppress noise and reverberation and thus lead to different results than conventional measurement methods in the presence of several spatially distributed sound sources. In addition, the outer ear is a direction-dependent filter, which modifies the sound pressure level in the range between -15 dB and +30 dB depending on frequency and angle of sound incidence. This means that it does make a difference in human hearing whether several sound sources come from the same direction of incidence or from different directions. In addition to the proper recording, the artificial head technology offers the following advantages in the sound reproduction:



- clearly defined noise
- can be repeated as often as desired
- direct A/B comparison
- can be stored indefinitely
- no distraction from the environment
- spatial impression

These advantages have led to the fact that the artificial head measurement and analysis technology is not only used in the automotive industry, but in addition to traditional sound measurement technology in a wide variety of industrial sectors, especially for the design of sounds. Hearing is a highly sensitive measuring system, but it does not have sufficient long-term memory. This means that if the human ear has classified a sound event unpleasant and annoying, this parameter is retained even if this noise has been reduced by 2 dB or 3 dB or even more. This means that once the human ear has become more sensitized to a specific sound event, the hearing is hardly able to reliably assess whether the sound quality or the noise exposure as a whole has changed. If the sound event consists not only of a single sound source, but of several sound sources, which are also spatially distributed, binaural signal processing is required for the correct assessment of a sound event. The binaural technology means the recording of sound with an artificial head measuring system and the inclusion of an evaluation algorithm comparable to human hearing. The simple physical measurands such as A-weighted sound pressure level and third octave spectrum do not provide complete information about the sound event.

The principle of head-related stereophony consists in the distortion-free measurement, transmission, and reproduction of sound pressure signals on the human eardrums. The directional pattern of the artificial head must correspond to the average directional pattern of the human being. The self-noise should be imperceptible in order to allow listening in the area of the hearing threshold. The dynamics should reach up to the pain threshold in accordance with the human ear in order to be able to detect all level peaks in a distorted manner. The system must be calibratable and compatible with conventional sound measurement technology.

Such a measurement system was developed based on the cooperation of an automobile manufacturer with the Institute of Electrical Communications Engineering at RWTH Aachen University, see Fig.1.

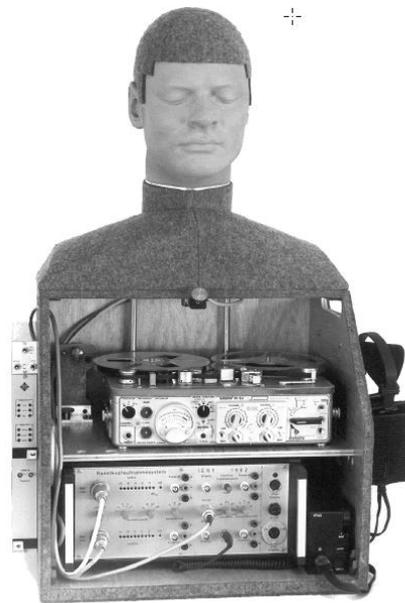


Figure 1. First calibratable, freefield equalized artificial head (Aachen Head) which was compatible to a measurement microphone [1].

In 1981, the first artificial head measuring system was developed with properties comparable to those of the human ear in terms of directivity, frequency transmission range and dynamics, which was also free-field equalized and calibratable for use in acoustic measurement technology [1]. It is primarily used for recording and analysis in the field of noise quality and sound design. Sound events are faithfully recorded and evaluated via headphones. On the one hand, it is possible to make easily audible comparisons of different products (benchmarking) or the acoustic effects of modifications to the product. On the other hand, signal processing can be used to manipulate individual components in the time or frequency domain in order to identify which properties lead to an annoying sound impression and how a desired sound can be achieved. In conjunction with psychoacoustic analyses, different noise situations can also be better documented with objectively describable quantities adapted to the auditory assessments.

The field of application of this improved artificial head measurement technology initially focused on the automotive sector, manufacturers as well as suppliers. Soon, however, also in the field of determining the sound quality of office and household appliances. In the meantime, the application has also been established in

room and building acoustics as well as for recording acoustic environmental pollution. The international standard ISO 12913 "Soundscape" requires the use of binaural measurement technology.

Very quickly, the advantages of a faithful reproduction of sound events became apparent during the application of binaural measurement technology: a direct comparison of different driving situations or of different vehicles or modifications was now very quickly possible even for inexperienced persons. Measures taken could be impressively demonstrated to the management without resorting to diagrams and measurement data evaluations that are difficult to understand.



Figure 2. PC-system with DSP-board to analyze sound like the human hearing combined with interactively manipulation of sound and psychoacoustic analysis [2].

Now that true-to-the-original sound recordings were available in digitized form, the idea and the desire soon developed to manipulate them with the help of digital signal processing in the time and/or frequency domain in order to be able to judge which features in the signal make the noise seem unpleasant or annoying (troubleshooting) or how the sound should be designed in order to be able to achieve the sound suitable for the product (sound design).

3. PSYCHOACOUSTICS

The psychoacoustic properties of human hearing like loudness, sharpness, roughness, fluctuation strength, pre-, post- and simultan masking determine the auditory sound impression. There was interest in using new parameters to make the audible sounds comparable with numerical values. This led to the integration of psychoacoustic calculation variables and thus the BAS -

Binaural Analysis System, see Fig. 2- was born, which enabled the comparative reproduction of artificial head recordings, their manipulation, and their calculation with DSP boards for online analysis and interactive manipulations in real time with a PC [3].

This combination of hardware artificial head recording and calibrated, equalized headphone playback system, DSP boards and software led to the founding of HEAD acoustics GmbH in 1986, which further developed this innovative approach to noise assessment and design worldwide and made it available to a wide range of applications. The practical applications led to consistent further developments: if it was now possible to quickly find out which signal components in the noise are responsible for annoyance and quality, the desire arose to recognize their sources and transmission paths in airborne as well as structure-borne sound. This led to the expansion of the previously two-channel measurement technology for binaural signals to a multi-channel measurement technology (SQLab) in order to record sources and transmission paths with microphones in the near field and with acceleration sensors at the force application points, see Fig. 3. In addition, other variables such as speed and engine speed were recorded [4].



Figure 3. Mobile portable multi-channel recording system to record not only the sound but nearfield microphones and accelerometer signals, too, including information about speed and rotation.

4. SIMULATION

The next evolutionary step lies in predicting how modifications to transmission paths will affect perceptible acoustics. In 1992, as part of a European-funded research project AQUSTA [5], binaural transfer path analysis and synthesis (Pro(g)noise) was developed in order to be able to interactively auralize changes in airborne sound transmission paths and/or altered impedances and stiffnesses binaurally. As early as 1996, the first sound car was introduced, which could simulate not only binaural signals, but also the vibrations perceptible in the seat and steering [6], see Fig. 4.



Figure 4. First acoustical driving simulator with vibration at seat and steering and interactively sound simulation based on transfer-path-analysis [7].

With over 450 employees, HEAD acoustics GmbH, with its headquarters in Herzogenrath and 8 subsidiaries worldwide, not only has its own hardware and software development, but also a large research and service area with several measuring rooms (four-wheel roller, 3-D anechoic room, etc.). HEAD acoustics is working intensively within several standardization committees such as DIN, ISO, ETSI, EMAC, ITU, CCITT.

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THE INSTITUTE OF SOUND AND VIBRATION RESEARCH AT THE UNIVERSITY OF SOUTHAMPTON

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ABSTRACT

The Institute of Sound and Vibration Research, ISVR, grew out of the Aeronautics Department at the University of Southampton in 1963. Although its focus was initially on noise and on vibration-induced structural fatigue in aircraft, there was already a recognition of the wider issues of sound in society and its medical effects. The ISVR was set up as a separate research institute due to the far-sightedness and determination of its founder, Prof Elfyn Richards, who had previously been Chief Aerodynamicist and Assistant Chief Designer at the Vickers Armstrong aircraft company. The engineering research interests of the Institute continued to develop as it rapidly expanded in the 20th century, to include aeroacoustics, bubble acoustics, audio, active control and railway noise and vibration. Whereas originally only about 20% of the ISVR academic staff were concerned with medical issues and human response, this figure has grown to be more like 60%, including audiology, cochlear implants and human response to sound and vibration, reflecting the growing importance of these aspects of sound and vibration.

Keywords: *research institute, sound, vibration*

1. HISTORY OF THE ISVR AND ITS BACKGROUND

Engineering departments at many universities in the UK were rapidly expanding in the 1960s, driven by the need for skilled people across many industries. In particular, the Aeronautics Department at Southampton had a vibrant research group on aircraft noise and vibration, which

became a separate research institute, the ISVR [1], in 1963, with five academic staff. The first Director was Prof Elfyn Richards, who had previously been Chief Aerodynamicist and Assistant Chief Designer at the Vickers Armstrong aircraft company, and after his time in Southampton would go on to be Vice-Chancellor of Loughborough University. In these early days, the ISVR began an MSc in Sound and Vibration Studies, and also Phil Doak became the founding editor of the Journal of Sound and Vibration.

Leading up to the 1960s there was a thriving and entrepreneurial aircraft industry in the UK, with many different companies competing in both the military and civilian aircraft markets [2]. The need to reduce aircraft noise levels from aircraft was clear [3], as was the need to understand vibration-induced structural fatigue, which had led to several catastrophic failures in the first commercial jet aircraft, the de Havilland DH.106 Comet [4]. There was also a wider concern about noise in UK society that led to the UK Noise Advisory Committee, the Noise Abatement Act in 1960 [5] and the comprehensive and highly influential report of the Committee on the Problem of Noise in 1963 (the ‘Wilson Report’) [6].

2. DEVELOPMENT OF THE ISVR

The ISVR expanded rapidly in the remainder of the 20th century. Its overall income increased exponentially, doubling about every six years, with about two-thirds of this coming from external research grants. There was also a corresponding increase in the numbers of academic and support staff and PhD students, and a widening of the research interests within the ISVR to include automotive noise and vibration, structural dynamics, underwater acoustics, hearing protection and communication, signal processing, human factors and active control. The Wolfson Unit for Noise and Vibration Control was founded in 1968 to provide more focused support for industry, and this, together with the Automotive Design Advisory Unit, was later renamed ISVR Consulting [7]. March 1968 also saw

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the opening of the Large Anechoic Chamber [8] and the two Reverberation Chambers [9] in the ISVR's Rayleigh Labs. There was also an increasing interest in the human aspects of sound and vibration, in particular biodynamics, audiology, and cochlear implantation, which led to the

formation of the South of England Cochlear Implant Centre, later the University of Southampton Auditory Implant Service (USAIS), in 1990 [10], who have now been involved in over 2,000 cochlear implantations.



Figure 1 . Pictures relating to the ISVR, left to right top to bottom: Cochlear implant, graduation, noise test on an aircraft engine, whale noise visualisation, fan noise measurement and audiology assessment

Whereas only about 20% of staff at the ISVR were involved in hearing and biomechanics in 1970, the figure now is about 60%. The ISVR was awarded the Queen's Anniversary Prize in 2005 with the citation for: "Improving the quality of life for the profoundly deaf and reducing noise pollution

1. ACKNOWLEDGMENTS

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THE ACOUSTIC CENTER OF ECOLE CENTRALE DE LYON

FROM 1970 TO TODAY

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ABSTRACT

The research team in acoustics at Ecole centrale de Lyon was created 50 years ago by Prof. Geneviève Comte-Bellot. In this paper we describe the growth of this team, known now as the Acoustic center of Ecole centrale de Lyon (or Centre Acoustique in French), from the early 70s to today. The evolution of the research interests and of the experimental facilities is emphasized, and a selection of “historical” references is given at the end of the paper. The main current research topics are also listed, illustrated and completed by a partial list of recent references.

Keywords: *Aeroacoustics, jet noise, fan noise, sound propagation, nonlinear acoustics.*

1. HISTORICAL PERSPECTIVE

1.1 The early years (1970-1980)

The acoustic team of the Fluid Mechanics and Acoustics Laboratory (LMFA) of Ecole centrale de Lyon was created by Prof. Geneviève Comte-Bellot (born in 1929) at the very beginning of the 1970s. This creation resulted from the vision of Geneviève Comte-Bellot, a world-renowned expert in the study of turbulent flows, that the new discipline resulting from the intersection between fluid mechanics and acoustics, or *aeroacoustics*, was

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destined for a very strong development, both in its fundamental aspects and in its applications, particularly in the aeronautical industry.

On the practical side, the construction of a silent wind tunnel associated with an anechoic chamber [1] was rapidly finalized, a first in France in the university context. The installation was completed by two coupled reverberation chambers used to measure the absorption coefficient of acoustic materials and the transmission loss of panels placed in the large opening connecting the two rooms. Fig. 1 gives the plan of the experimental installation located in a basement to limit the transmission of parasitic noise. A first experimental paper [2] appeared very quickly, in which cross-correlations between surface pressure and acoustic far-field were used to characterize airfoil noise.

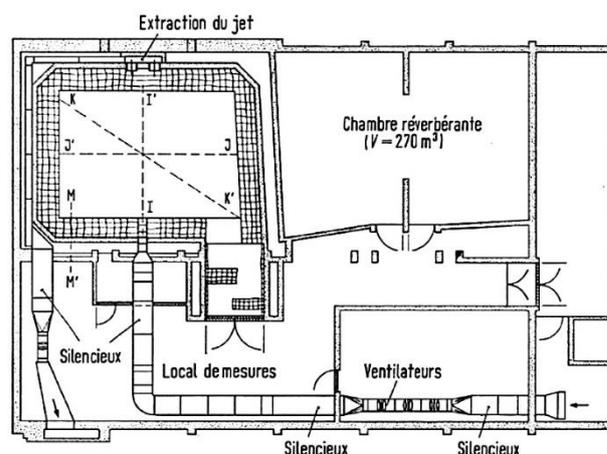


Figure 1. The experimental facility in the early 70s, see ref. [1].

The initial research topics focused on the noise of fans and of their basic components, airfoil or blade profiles. The operational team then consisted of only two members, Prof. Michel Sunyach and a young Assistant Prof., Henri Arbey. In 1974, the installation was completed with the construction of a wind tunnel intended for the study of the noise generated by subsonic jets (D. Juvé, [3]).

The research themes quickly widened to the diffusion of sound by turbulence (D. Juvé-M. Sunyach, 1976), then to the propagation of high frequency sound waves through an extended zone of kinematic or thermal turbulence (Ph. Blanc-Benon-D. Juvé, 1978 [4]).

The initial research activities centred on airfoil noise were supplemented by the study of aircraft compressor noise (M. Roger-H. Arbey, 1980, [5]).

1.2 Creation of the Acoustic Center (1980s)

Very rapidly, the characteristics of the initial installation proved to be too limited for foreseen applications, the Mach number being restricted to 0.4 for small diameter jets (typical diameter of 2cm) and to 0.2 for the noise of airfoil profiles placed in the potential core of a rectangular jet (section of 30cmx10cm).

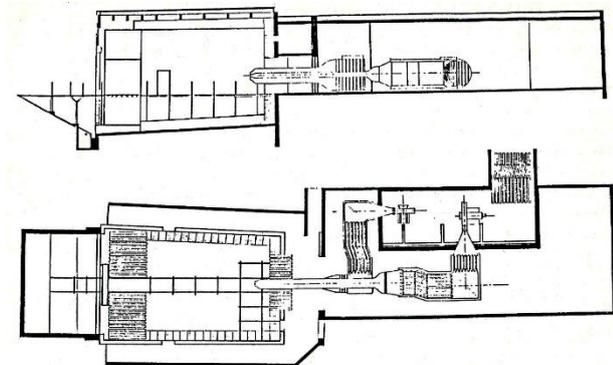


Figure 2. The experimental facility of the Acoustic center in the 80s, [6].

From the end of the 1970s, G. Comte-Bellot sought the necessary funding to create a world-class facility, complete with the measurement rooms and offices needed to increase the size of the team. The construction of a new building began in 1980 and the official inauguration of the Acoustic Center of Ecole centrale de Lyon was carried out in 1985 on the occasion of the holding of the IUTAM symposium

“Aero and Hydro-Acoustics”, organized by G. Comte-Bellot and J.E. Ffowcs-Williams.

A large anechoic chamber (10m x 8m x 8m) was coupled to a wind tunnel allowing a Mach number of 0.5 to be reached in a section of 0.4m x 0.2m. A second fan fed a half-velocity flow into jets adjacent to the main stream and intended to enhance the emergence of the noise from airfoils placed in the potential core of the primary jet (Fig. 2). The detailed characteristics of the installation are described in reference [6]. A compressor to power a supersonic jet stream was part of the original plan but could not be installed due to insufficient funding.

To the noise studies of fans, airfoils and obstacles of more complex shapes, was added that of the excitation of structures by flows: measurement of wall pressure fluctuations under turbulent boundary layers and of the resulting vibrations of flexible plates and, somewhat latter, of pipes (G. Robert, [7], [8]).

In parallel, under the impetus of M. Sunyach, the possibility of active strategies was developing to reduce noise in ducts or control combustion instabilities, (M-A. Galland, [9], [10], [11]).

1.3 The development of numerical simulation (1985-2005)

Researches in the Acoustic Center were initially focused on experimentation and theoretical modelling. They have gradually been extended to numerical simulation. The first works were directed toward the propagation of acoustic waves in random media, using first ray techniques and then parabolic approximations: interaction of acoustic waves with kinematic turbulence [12], sound propagation in the atmosphere [13] and nonlinear effects [14].

With the arrival of C. Bailly (1995), soon joined by C. Bogey, the team quickly turned to the simulation of acoustic propagation in high velocity flows [15]. Then the direct simulation of the generation of noise by turbulent flows was developed, based on the resolution of the compressible Navier-Stokes equations using high-precision discretization schemes in time and space developed by the team. The flows studied were high Mach number subsonic jets [16] (Fig. 3), but also cavity flows [17]. Supersonic jets, airfoils and turbulent boundary layers were then considered by the team.

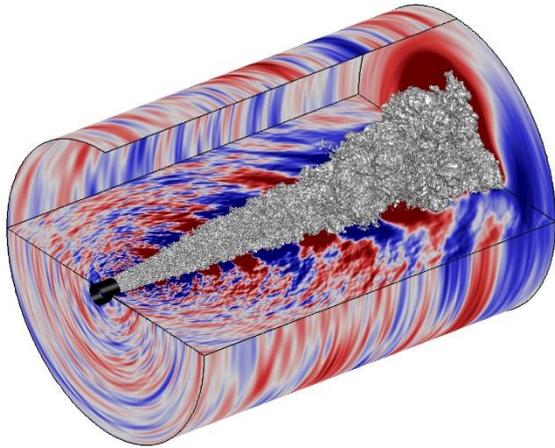


Figure 3. Direct numerical simulation of the vorticity and sound pressure of a jet at high Reynolds and Mach numbers.

2. CURRENT FACILITIES

If the structure of the buildings has remained substantially the same over the years, the experimental facilities have been constantly improved to allow the extension of research possibilities.

In 1994, the installation of a centrifugal compressor allowed the study of supersonic jets up to a Mach number of 1.5, with applications in the aeronautics and space sectors.

Very recently, the replacement of the coating of the walls of the anechoic chamber and the installation of a two-stage high-pressure blower allowed the study of the noise of airfoils and of wall-pressure fluctuations under turbulent boundary layers in the high subsonic regime (Mach number up to 0.7), where compressibility effects become very important. The joint use of the blower and of the centrifugal compressor also enables the study of the noise generated by coaxial jets, with a subsonic or a supersonic primary stream.

A schematic 3D view of the new facility is given in Fig. 4. The interior of the anechoic chamber is also shown in Fig. 5, in which the exhausts sections of both the subsonic and supersonic wind tunnels can be seen.

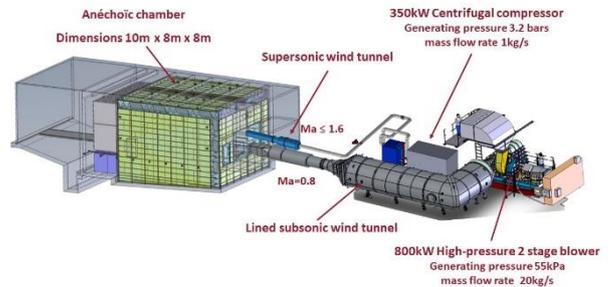


Figure 4. 3D schematic view of the main experimental facility of the Acoustic Center (blower and compressor, wind tunnels and anechoic chamber).

Other additional facilities have also recently been built. For fundamental studies, a low Mach ducted fan test rig was instrumented with both external and internal large microphone arrays (LP3 test bench, displayed on Fig. 6).



Figure 5. Internal view of the anechoic chamber and of the exhausts of the subsonic and supersonic wind tunnels.

Another test bench is also used to study the performance of passive and active materials in ducts with flow (Mach < 0.3) under multimodal excitation.



Figure 6. Partial view of the LP3 test bench, with emphasis on the 89 microphone external array. (The black half sphere is a (porous) Turbulent Control Screen used to reduce incident fluctuations in the sucked flow).

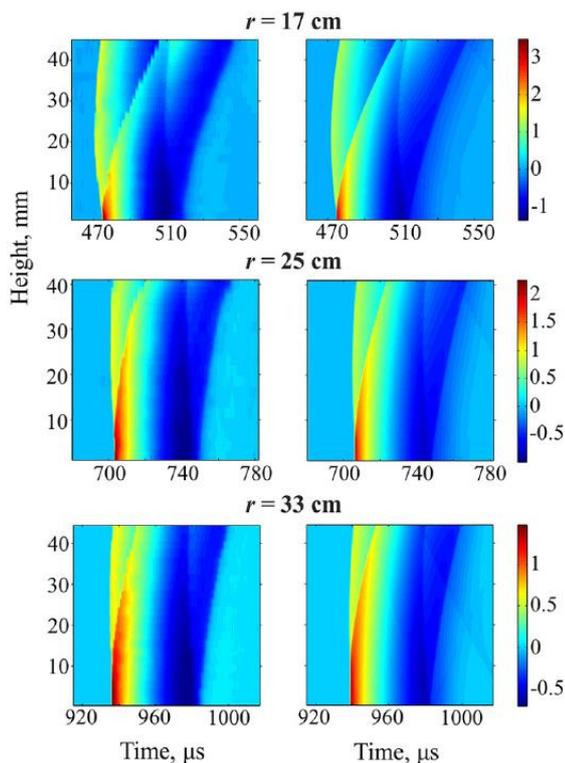


Figure 7. Reflection patterns of spark-generated shock pulses measured by a Mach-Zehnder interferometer (left) and numerically simulated (right), [24].

A facility for studying non-linear sound propagation was developed in which innovative optical measurement techniques (Schlieren and Mach-Zehnder interferometry) are used to characterize weak shock waves created by electric arcs. This facility is used in particular to simulate the propagation of sonic booms in the atmosphere and their interaction with buildings and a realistic ground topography.

A comparison between measurements and numerical simulations using non-linear Euler equations is given in Fig. 7.

On the more applied side, the team is strongly involved in studies carried out on the Phare-B2 test bed. This installation, engineered in partnership with Safran Aircraft Engines, reproduces the operation of an aeronautical fan on a 1/3 scale, and develops a power of 2MW (Fig. 8). Thanks to an anechoic environment, the external radiated noise can be measured and correlated with internal in-duct sensors. The innovative array techniques developed on the LP3 rig can then be transposed to this quasi-industrial installation.

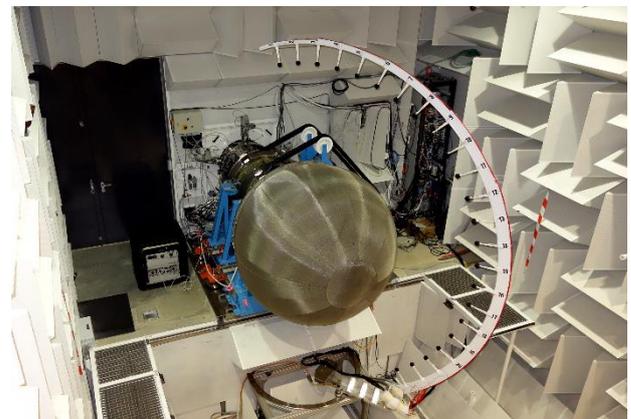


Figure 8. Phare-B2 facility. Partial view of the anechoic chamber and of the external microphone array (the inlet of the compressor is hidden by the TCS).

3. COLLABORATIONS AND RESEARCH PHILOSOPHY

Since its creation and until today, the philosophy of the Acoustic Center has been to achieve a harmonious balance between basic research and applications. The link with the industrial environment has always been

very close, especially with that of transport, whether automotive (Renault, Stellantis), rail (Alstom, SNCF) and of course aeronautics (Dassault, Airbus, Safran) and space (CNES, ArianeGroup). These links facilitate access to sources of financing necessary for the development of experimental facilities, in addition to national or regional public funds. They also constitute a source of difficult and interesting problems to deal with, after the search for an adequate schematization allowing the highlighting of the physics of the main phenomena involved. The very close relationship with Safran notably enabled the construction of the Phare platform (rotating machinery platform for environmental risk control) as well as the improvement of the performance of our large anechoic wind tunnel via the creation of two industrial chairs co-funded with the French National Research Agency (ANR).

On the university level, many international collaborations have been built over the years, with for example Cambridge, Johns Hopkins, Penn State, Austin or Moscow State, as well as with many European teams through participation in European programs from the very beginning of the 90s. These close collaborations made possible the organization of important international conferences, such as Euromech 142 “Acoustics of turbulent flows” in 1982, the IUTAM “Aero- and Hydro-Acoustics” symposium in 1985, several Long Range Sound Propagation symposia (LRSP 1996, 2008, 2018), an International Symposium on Nonlinear Acoustics (ISNA 2015) and the Aeroacoustics 2016 conference of the Council of European Aeronautical Societies and the American Institute of Aeronautics and Astronautics.

Regional and national collaborations have always been in the spotlight with the aim of federating strengths and skills. In the 1980s, G. Comte-Bellot was at the origin of a CNRS research group associating research teams in Lyon (LMFA and ICPI-now CPE), Grenoble (Cephag-now Gipsa-Lab) and Marseille (LMA). In Lyon, this desire for cooperation led to the creation in 1980 of the DEA (i.e. Master degree) in acoustics associating ECLyon with INSA and the University of Lyon I. In 2018 this was transformed into an International 2-year Master of Science in Acoustics from the University of Lyon, taught in English. This Master of Science relies strongly on the teams of the CeLyA (Centre Lyonnais d'Acoustique) Laboratory of Excellence. Created in 2011, this LabEx is the only

one in France focused exclusively on acoustics. Headed first by Daniel Juvé, then since 2018 by Etienne Parizet, it brings together all the main research teams from Lyon and Saint-Etienne. It covers many areas ranging from physical acoustics (vibroacoustics, aeroacoustics, ultrasound), to medical applications, sound perception, neurosciences and bioacoustics. CeLyA's teams and work are described on the website <https://celya.universite-lyon.fr/>.

4. THE ACOUSTIC CENTER TODAY AND TOMORROW

Composed of only 2 researchers in 1973, the Acoustic center is currently made up of 21 permanent staff and around 25 doctoral and post-doctoral students. A group photo of team members is given on Fig. 9. 168 PhD theses have been defended to date, and more than 400 articles have appeared in the best international journals.



Figure 9. Team members at the occasion of a group seminar in July 2021.

The complete list is available on the website <https://acoustique.ec-lyon.fr/>, where the majority of the texts of the articles and presentations at conferences can be found.

We give below the list of the main research topics currently treated together with references to related papers and a selection of illustrations of experiments or numerical simulations:

- **Aeroacoustics of free flows** [18], [19], Fig. 10.

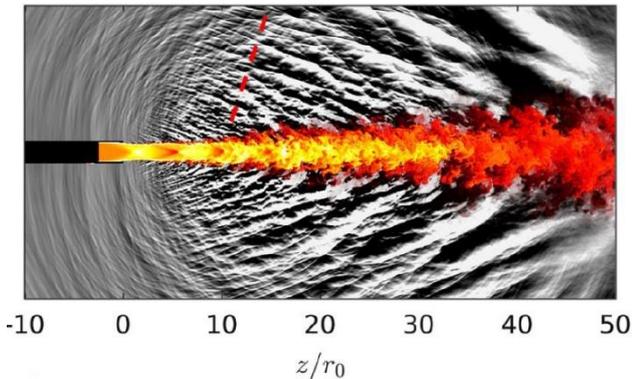


Figure 10. High Mach number supersonic jet: Snapshot of temperature fluctuations inside the flow and of pressure fluctuations outside, [19]. (The red dotted line indicates the direction of propagation of Mach waves).

- **Aeroacoustics of airfoils and turbomachinery** [20], [21], Fig. 11.

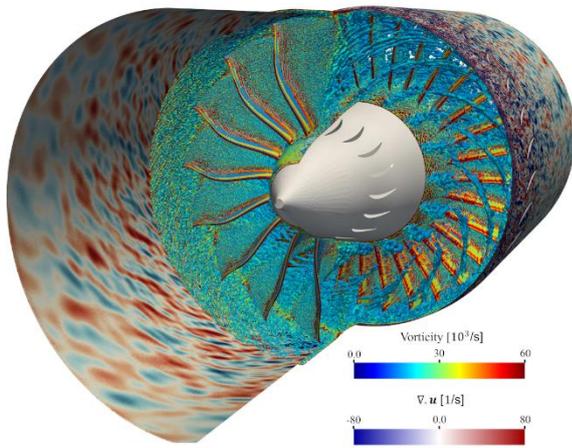


Figure 11. Ultrahigh bypass ratio fan. Instantaneous contours of the dilatation rate at 99% of the rotor span and iso-surface of the Q-criterion colored by the vorticity magnitude, [21].

- **Wall-pressure fields and excitation of structures by turbulent flows** [22], [23].

- **Linear and non-linear acoustic propagation** [24], [25], Fig. 12.

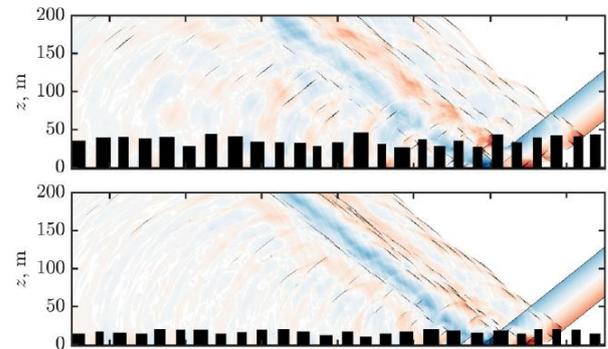


Figure 12. Numerical simulation of sonic boom propagation over urban areas, [25].

- **Bubble dynamics and medical applications** [26], [27], Fig. 13.

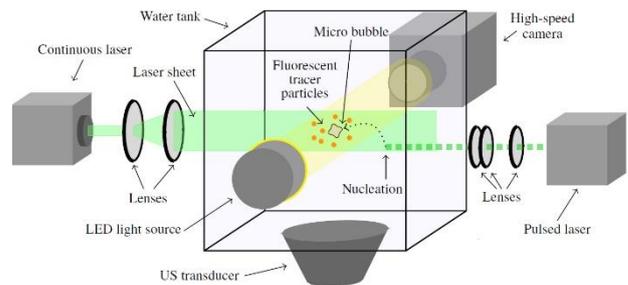


Figure 13. Microstreaming induced by oscillating microbubbles: Schematic of the experimental setup, [26].

- **Active and passive acoustic materials under grazing flow** [28], [29], Fig. 14.

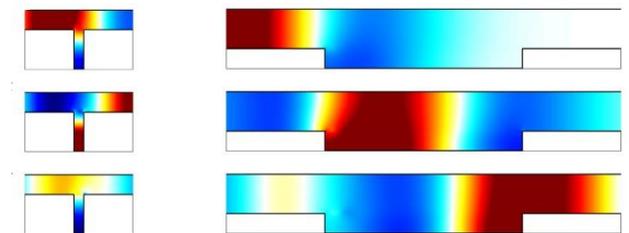


Figure 14. Time-domain simulation of sound propagation in a flow duct with extended-reacting liners: successive snapshots of the pressure field, [28].

- **Innovative optical measurements: Schlieren imaging, interferometry, Rayleigh scattering** [30], [31]

- **Innovative microphone arrays techniques, inverse problems, 3D sound field reconstruction** [32], [33], [34], Fig. 15.

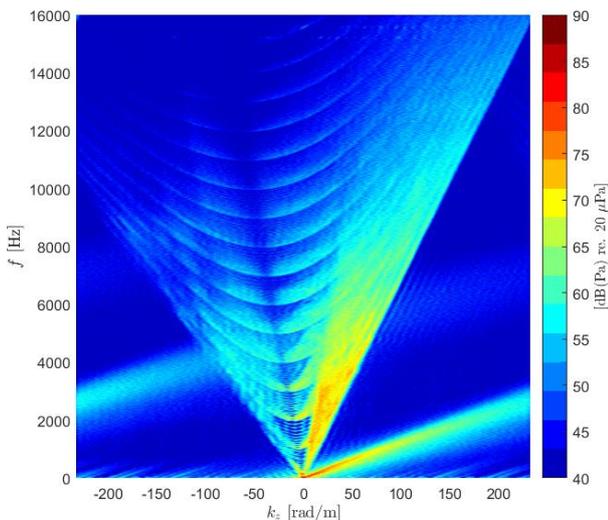


Figure 15. Wavenumber-frequency analysis of in-duct fan broadband noise using a Bayesian approach, [34].

5. ACKNOWLEDGMENTS

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ACTIVITIES IN ACOUSTICS AT LE MANS UNIVERSITY

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ABSTRACT

Since the middle of the 20th century, acoustics departments have been established in universities and engineering schools throughout France. Similarly, since the founding of the University of Le Mans in 1965, several research departments have been created, with increasing focus on acoustic research and teaching. In this context, the Laboratoire d'Acoustique de l'Université du Mans (LAUM) was established in 1981 and has grown from 3 to 90 faculty and CNRS members (including 25 staff), with 80 research graduate and post-graduate students. The LAUM's research areas have also expanded to include Electroacoustics, Materials, Waveguides and Structures, fostering cutting-edge research and international collaboration. The university and CNRS provide extensive infrastructure, specialized equipment, and support services to facilitate research efforts. Bachelor and master's level courses in acoustics provide students with opportunities to pursue careers as high-level technicians or engineers in the private sector or to prepare for a Ph.D. in acoustics.

Keywords: *Acoustics, Research, History*

1. INTRODUCTION

In France, during the mid-20th century, certain universities and schools began to establish research departments and teaching modules dedicated to acoustics. This was done in response to the growing need for engineering and training activities that could meet both industrial and societal demands. Notably, Le Mans emerged as a hub for such initiatives, with the establishment of university courses in Humanities, Law, Economic Sciences, and Sciences (Mathematics, Physics, Chemistry, Computer Sciences,

Biology and Geology). Since the construction of the first premises on the current campus around 1965, research laboratories have been established every year.

Against this backdrop, the Laboratoire d'Acoustique de l'Université du Mans (LAUM) was created during the academic year 1980-81 under the aegis of the Faculty of Sciences and the Department of Sciences for Engineering of the CNRS. This was built upon the initial works on electrodynamic loudspeakers and their radiation that were carried out within the "Service de Physique" during the 1970s and 1980s.

2. THE FIRST YEARS (1981-95)

In the early years of the laboratory, several researchers and teacher-researchers from diverse backgrounds, including theoretical physics, graduate schools, and engineering schools, gradually joined the projects initiated by the first two teacher-researchers. This influx started with two returns from French cooperation abroad and an internal transfer to the CNRS, which was made possible by obtaining the status of UMR (Mixed Unit of Research) after four years of the laboratory's existence. The continued arrival of new researchers and teacher-researchers allowed the laboratory to grow its staff to 8 CNRS researchers, 15 teacher-researchers, 4 engineers/technicians, and 2 secretaries, totaling 40 members, including doctoral students, by 1995. This number has continued to grow since then (see below).

A postgraduate course in acoustics has been developed with the support of the laboratory and a community of external French laboratories. The program attracted students from « Grandes Ecoles », engineering schools, French and foreign universities, all of whom have diverse scientific backgrounds.

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The laboratory's research means, including materials and financing, were pooled in accordance with contracts, a practice that remains highly valued to this day. Similarly, the means attached to the postgraduate course were shared between associated laboratories.

During this period, the choice of research methods and topics required caution as the laboratory had to find its way in a national and international context already well advanced in many fields. Therefore, the laboratory developed analytical and experimental methods from the start, with numerical methods only becoming prominent after dedicated recruitments. In addition, the laboratory had to choose relatively original research topics, distinct from those widely studied at the time. Consequently, the laboratory focused on electroacoustics (transducers) and acoustic materials (particularly porous materials) initially, then waveguides (wind musical instruments and exhaust silencers) and room acoustics when new researchers arrived, and finally audio signal processing.

A policy of contracts has been in place since the beginning of the laboratory (industrial contracts on modeling and metrology of porous materials, silencers for the automobile industry, acoustic control of bonding, ...) allowing to support the more fundamental research. In parallel, academic collaborations in France and abroad have been progressively established. These collaborations include ongoing partnerships with universities such as Louvain, KTH Stockholm, EPFL Lausanne, Valencia, Athens, Sherbrooke, Harvard, MIT, Santiago (Chili), Sfax, Hokkaido, UST Hong Kong, Auckland and around thirty other establishments. The laboratory also collaborated with the Technical University of Prague during a time when the Iron Curtain was still in place, which complicated the process of crossing the border with scientific equipment...



Figure 1. An experimental room of the LAUM in the 80s

At the beginning of the laboratory, an anechoic room was built with funding from the regional council. It adjoined the existing physics building and was connected to the

available basements. Industrial contracts signed at the outset of the laboratory provided most of the equipment and operational costs. A whole apparatus of precision measurement, mainly analog, was acquired, and a system of connections between the rooms of experiments was set up to allow for shared use. Other infrastructures and means were established on the campus during this period, including the Acoustics department (independent of the LAUM) of the Centre de Transfert de Technologie du Mans (CTTM) created in 1992. It was equipped with a large anechoic room (1000 m³) coupled with a reverberation room. The engineering school (ENSIM) created in 1995 also had rooms for optical holography, vibrations, and microtechnologies integrated into the LAUM. Equipment dedicated to teaching was also established, including that of the Bac+2 course of study (DEUST "Vibration, Acoustics, Signal") created in 1990, which has trained over 500 technicians in acoustics in 20 years of existence and was highly valued by industrialists.



Figure 2. Anechoic room experiment

3. THE YEARS 1995 - 2023

Since the mid-1990s, the LAUM has experienced continuous growth in its staff, expanding from 40 to 170 members in 2023, including some colleagues based at Electronic engineering school ESEO in Angers. This growth has naturally led to the emergence of new research themes, owing to the evolution of research in general, as well as the diversity of recruitment. The laboratory has welcomed researchers and teacher-researchers with diverse backgrounds in acoustics, physics, mechanics, optics, thermics, micro-technologies, digital methods, applied mathematics, electromagnetism, electronics, and signal processing. Although the structure has remained largely on the model of three teams (Transducers, Materials, Guided Waves), the topics within these teams have gradually

become more diverse and enriched. Aeroacoustics, granular materials, vibro-acoustics, thermoacoustics, ultrasound, instrumentation and metrology, meta-materials, opto-acoustics, and other topics have been developed. These developments span a broad spectrum from the most fundamental studies to partnership research, while maintaining a balance between theoretical (analytical and numerical) and experimental studies.

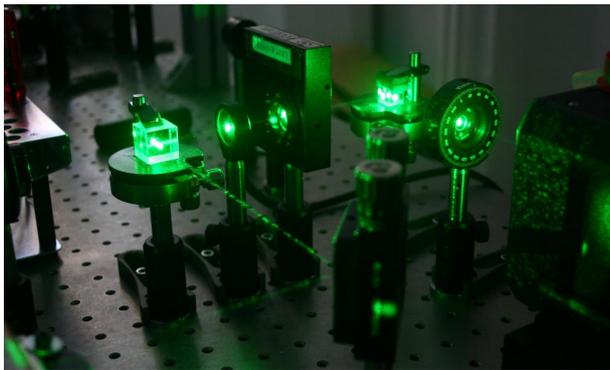


Figure 3. Opto-acoustic experiment

To illustrate the above discussion on the research topics, let's now focus on a few of them. The four research topics chosen by the laboratory from the outset (electroacoustics, materials, guides, and rooms) shared a same physical phenomena: thermoviscous effects, and more specifically the phenomena that take place in the thermoviscous boundary layers. The advances achieved in these research topics are based on their revisited and dedicated analytical formulations, compared against the classical available formulations, even though these classical formulations covered most of the aspects of the phenomena involved. Then, on these analytical bases, the research topics were, on the one hand, extended (new materials, flow effects, transducer non-linearities, etc.) and, on the other hand, they introduced new concepts including i/ thermoacoustics (exploiting thermal boundary layers) which arose from US laboratories and was further developed substantially at LAUM in collaboration with the LMFA at ECL in Lyon, and ii/ acoustic "gyrometry" (exploiting viscous boundary layers), which arose from and was developed at LAUM. In addition to the analytical and experimental work required by these projects, numerical methods (finite elements) and construction of prototypes, including miniature prototypes (MEMS, from 1989-90), were developed at LAUM. It is obvious that these research orientations have been funded by state and private contracts because of the potential applications. Today,

these studies are being expanded in several directions: boundary effects of gas mixtures and phase changes, and dedicated numerical methods (finite elements) for each of the problems considered.

The LAUM has established numerous industrial collaborations, some of which have been long-term partnerships, including research contracts, patents, and industrial PhD thesis. Currently, the laboratory collaborates regularly with companies in the transportation sector (including automotive, aeronautics, rail, and space), as well as those in the building and audio industries. Furthermore, the LAUM's research activities are consistently supported by various research agencies such as ANR and Actions Marie Curie.

In 2015, the LAUM made a strategic decision to expand its international collaborations, particularly through the implementation of the "Acoustics Hub" program. This initiative was conceived by the laboratory and financed by the Pays de la Loire Region. The program enables foreign researchers to undertake regular research stays at the LAUM, ranging from several weeks to several months, thereby transforming the laboratory into a "hub" for researchers from all around the world to come together and collaborate.

The LAUM showcases its research through publication in leading international peer-reviewed journals, averaging around 100 publications per year in the fields of acoustics and physics. Thanks to the "Acoustics Hub", over 50% of these publications have involved collaborations with international colleagues, highlighting the laboratory's growing emphasis on international cooperation.

Simultaneously, the LAUM has expanded its training offerings over the last three decades. With the Bologna Process introducing a three-cycle higher education system, the DEUST program was transformed into a Bachelor of Acoustics, and a Master of Acoustics was created, with a "research" option corresponding to the former Postgraduate Course in Acoustics. This master has been further enriched by other options, such as the Master "Environmental Acoustics », the International Master of Electro-Acoustics (IMDEA), which was launched in 2011 and co-financed by a private foundation managed by the Institut de France, and the International Master "Wave Physics and Acoustics," which was opened in 2020. For these two international masters, all courses are taught in English. Currently, the Le Mans campus has approximately 500 students in acoustics at all levels (from Bac+1 to Bac+8) each year. In 2018, a University Research School called the "Institute of Acoustics - Graduate School" (IA-GS) was established. Modeled after the Anglo-Saxon

"graduate schools," it integrates the laboratory and the training of masters, engineers, and doctorates in acoustics into a single structure. One of its primary objectives is to develop research training by welcoming students into the laboratory at an early stage of their studies. This is especially true for the Master "Wave Physics and Acoustics," which substitutes research projects in the laboratory for part of the in-depth lectures.

The growth of the LAUM has also led to an expansion of its facilities. In the early 1990s, the ENSIM building and the physics building of the Faculty of Sciences were constructed. Currently, a new building is being built that will include additional experimental surfaces, new rooms dedicated to acoustics training, and a space for scientific dissemination/exhibition. Moreover, a new Techno-Campus "Acoustics and Matter" building is near completion, with delivery scheduled for September 2023. Its purpose is to house industrialists who wish to set up their businesses near the University's research laboratories. The building will include two of the LAUM's major facilities: the 3DVIB platform, which consists of three laser vibrometers mounted on a robotic arm for measuring complex vibration fields on large structures, and the MAINE FLOW multimodal aeroacoustic test bench for studying the interactions between acoustic materials and flows under conditions close to those encountered in an aircraft engine (Mach 0.6, 150 dB).



Figure 4. The test section of the "Maine Flow" aeroacoustic bench

The LAUM has always prioritized actions for the collective, both in its internal operations and in its relationships with partners. Several members have taken on collective responsibilities at the local level (such as leading Ensime, the Faculty of Sciences, and the University) and at the national level (through participation in the National Council of Universities and the National Committee of the CNRS). It is also heavily involved in the

French Acoustics Society (SFA), regularly organizing or co-organizing congresses (CFA 2000 and 2016), study days, and summer schools.

Since 2014, the LAUM has been working towards bringing together the various actors of acoustics in Le Mans under one banner. This effort has resulted in collaborations with the Institut Technologique Européen des Métiers de la Musique (ITEMM), the Superior School of Art and Sound Design of Le Mans, and the Centre de Transfert de Technologie du Mans (CTTM) for research, development, and training. It has also partnered with cultural organizations in Le Mans for "art and science" projects. In collaboration with the City of Le Mans, this consortium of acousticians has created an event for the general public called "Le Mans Sonore". This event, which combines science and culture, has now become an international biennial of sound. The third edition of this biennial will take place in January 2024, featuring unusual visits of the laboratory, exhibitions for the general public, and scientific workshops. Sound artists and designers are also invited to participate and highlight certain aspects of LAUM's research.



Figure 5. The future Acoustics building (in the background, the LAUM building of the Faculty of Sciences)

4. KEYS TO THE FUTURE

It goes without saying that the lab is the fruit of communal endeavor of all the staff and of the input of generations of graduate and postgraduate students. During its 42 years of existence, it has been enriched by a friendly work environment and a continuous sharing of its life by everyone. It recently celebrated its 40th anniversary during a studious and friendly weekend; it's time to plan its 50th anniversary celebration in the same spirit!



HISTORY OF THE LABORATORY OF MECHANICS AND ACOUSTICS IN MARSEILLES (FRANCE): FROM THE SECOND WORLD WAR TO THE PRESENT DAY

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ABSTRACT

The Laboratory of Mechanics and Acoustics in Marseille (France) celebrated its 80th anniversary in 2021. It was created in 1941, under the name of *Centre de Recherches Scientifiques, Industrielles et Maritimes* (CRSIM) and was the successor of the French Naval Research Center created in Toulon by the French Navy, under the direction of François Canac, to work on submarine detection during World War I. It was the first laboratory of the National Center for Scientific Research out of Paris. In this laboratory, Paul Langevin developed the first high-powered ultrasonic transmitters for the detection of submarines. F. Canac headed the CRSIM until 1958. He was one of the founders of the journal *Acustica*. The acoustics service developed considerably under his leadership. The CRSIM became the *Centre de Recherches Physiques* (Physical Research Center, CRP) in 1962 and was directed by Théodore Vogel. In 1973, the laboratory had a Department of Mechanics and a Department of Acoustics. On July 10, 1973, the laboratory took the name of *Laboratoire de Mécanique et d'Acoustique* (LMA, Laboratory of Mechanics and Acoustics), a name that better describes its activities and which it still bears today. We present here the evolution of the laboratory's research themes over these 80 years.

Keywords: *Acoustics, Mechanics, history*

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1. INTRODUCTION

The Laboratory of Mechanics and Acoustics is, at its name indicates, specialized in mechanics and acoustics. It is composed of about 130 people (researchers and teacher-researchers, engineers, technicians, administrative staff, doctoral students). It is a research unit attached to *Aix-Marseille University* (AMU), the National Center for Scientific Research (Centre National de la Recherche Scientifique, CNRS) and the *École Centrale Méditerranée*. Its origin dates back to the beginning of the 20th century, but it has been a CNRS laboratory for "only" 80 years. This text is strongly inspired by the writings of Claude Gazanhes ([1], [2]).

2. THE VERY BEGINNING

The origins of the laboratory go back to the *Laboratoire de la Guerre Sous-Marine* (Submarine Warfare Laboratory), created in Toulon in 1917 by the French Navy. It was in this laboratory, among others, that Paul Langevin developed the first high-powered ultrasonic transmitters for the detection of enemy submarines by echoes.

At the end of the war, in 1920, the missions of this laboratory grew; it became the *Laboratoire du Centre d'Etudes de Toulon* (Laboratory of the Toulon Study Center, LCET) and its scientific direction was entrusted to François Canac who played a major role in the history of the laboratory of which he was the founder and then the director until 1958.

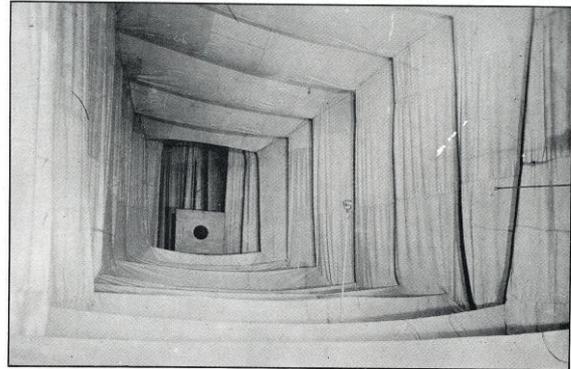
For F. Canac, inspired by the National Physical Laboratory, Teddington (UK), the objective was that the LCET, well beyond its missions for the French Navy, should be an organization of upstream research and "technology watch",

capable of developing, for a government department or industrial sector, applications resulting from the latest discoveries, of building prototypes, what is called today “technology transfer”.

3. THE SECOND WORLD WAR

At the beginning of the Second World War, the laboratory was renamed *Centre de Recherches de la Marine* (CRM). At the end of June 1940, the CRM, staff and equipment, was hurriedly embarked on a ship to Oran and then a train to Algiers. It seemed that the CRM would disappear in the turmoil. But it was headed by an energetic man with a strong personality. In August 1940, F. Canac proposed that the laboratory be placed under the supervision of the Ministry of Public Instruction: "The working methods (of the laboratory) are precisely those which it is necessary to introduce (very thorough research, complete development in view of pragmatic problems). It would bring its specialists, its material, its documentation".

F. Canac's appeal was heard. The CNRS had just been created; its administrative and financial situation was still under study but everything happened very quickly. On January 1, 1941, the CRM became the first “Laboratoire Propre” (i.e. with a unique supervision) of the CNRS out of Paris and took the name of *Centre de Recherches Scientifiques Industrielles et Maritimes* (Center for Scientific, Industrial and Maritime Research, CRSIM). The research at CRSIM was divided into five major themes: Acoustics, Optics, Chemistry-corrosion, X-rays, Psychotechnics. The Acoustics part was strongly developed, notably under the influence of F. Canac who was passionately interested in the Acoustics of the Ancient Theaters [3]. It included electroacoustics, vibrations, architectural acoustics, ultra-sounds in air and water. The CRSIM already had many facilities: a large anechoic chamber (13 x 5 x 5 m³), a small anechoic chamber (4 x 2 x 2 m³), a reverberation room (10 x 2.6 x 2.6 m³), a ripple tank for the study of room models, a 18 m channel with an absorbing basin. Figure 1 presents a view of the large anechoic chamber and reminds us of the difficulties of the time: the absorbing walls were made of pyramidal trunks covered with blankets supplied by the Health Service (Figure 1).



Chambre sans écho.

Figure 1: the anechoic chamber of the CRSIM

4. THE CRP (PHYSICAL RESEARCH CENTER)

In 1962, the CRSIM became the *Centre de Recherches Physiques* (Physical Research Center, CRP) with 4 departments: Mechanics Physics and Acoustics, Wave Visualization, Automation, Structures of crystalline bodies. The laboratory moved to the *Joseph-Aiguier* site, still in Marseille, where it joined other CNRS laboratories. Thanks to this operation, the laboratory grew and benefited from the installation of new important and powerful equipment for acoustics: among others, a large anechoic chamber for the wave propagation, a smaller anechoic chamber for psychoacoustic tests, a station for architectural acoustics built according to international standards and including two adjacent reverberant rooms for studying the acoustics transparency walls, a music studio with a piano, several tanks dedicated to underwater acoustics and ultra-sound propagation.

5. THE LABORATORY OF MECHANICS AND ACOUSTICS

In 1975, the laboratory refocused on Solid Mechanics and Acoustics and became the LMA. Mechanics of continuous media, computer science, and real time techniques has developed from this time as well as experimental facilities for mechanics.

The acoustics department was composed of 5 teams: acoustic theories, applied acoustics, aerodynamic acoustics, musical acoustics and propagation in liquid media.

Later, new themes would appear like ultrasounds, protection of environment, active noise control and psychoacoustics (which was part of the research themes of

the CRP but has been abandoned for more than 10 years), submarine acoustics.

In 2012, the *Laboratoire de Contrôle Non Destructif* (Non-Destructive Control Laboratory, LCND), based in Aix-en-Provence (at Aix-Marseille University), joined the LMA. Since then, the LMA has a branch and premises at the IUT in Aix-en-Provence (Mechanical Engineering Department). At that time, the laboratory was restructured into 3 teams (described below) which continue today.

In 2015, the LMA moved to the *Technopôle de Château-Gombert* where the fluid mechanics and physics laboratories, as well as the engineering schools *École Centrale Marseille* (now *École Centrale Méditerranée*) and *Polytech-Marseille*, were already present.

The new laboratory offers an exceptional experimental environment, that was designed by its staff during the construction project. In particular, a set of 3 anechoic rooms represents a rare equipment in the community: an anechoic room equipped with the necessary cabling for the study of active anechoicity at low frequency (Figure 1); a semi-anechoic room coupled with an excitation room underneath it (where complex sounds are made), designed to accommodate large-scale projects directly related to industrial applications; an anechoic room that can receive participants for psychoacoustic experiments.

Today the LMA is composed of 3 teams: *Materials and Structures*, *Waves and Imaging*, *Sounds*. The work of the *Materials and Structures* team concerns solid mechanics, with experimental, theoretical and numerical aspects. The objectives of its activities range from the characterization of materials or structures (fatigue behavior for example) to the establishment of models or innovative modeling tools to simulate solid media (materials, structures or interfaces). The research conducted in the *Waves and Imaging* team aims at developing acoustic methods for modeling, characterization and/or imaging of heterogeneous media with fundamental and applied approaches. The research carried out in the *Sound* team concerns audible sounds: their production, propagation, control, synthesis and listening. Since the studied sounds are audible, Human remains an important element of the scientific context, either he/she participates in the production of the sound (sung voice, musical instruments), or he/she undergoes its nuisance (transport noises), or he/she uses it on purpose (communication). And the human being is also the object of the research (perception, hearing).



Figure 2: the large anechoic room of the LMA at *Château-Gombert*

6. ACKNOWLEDGMENTS

We would like to thank Alain Rimeymeille for the pictures.

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ACOUSTIC ACTIVITIES AT CSTB IN THE 20th CENTURY AND BEYOND

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ABSTRACT

The Acoustic Department was created in the sixties around an acoustic test laboratory. From the beginning CSTB has been involved in improving acoustic performance for building occupants.

It played an important role in technically supporting the French acoustic regulation (first one in 1968 and last one in 1995) and in developing solutions to reach mandatory building performances in cooperation with the industry.

The acoustic department grew fast becoming the largest acoustic team in France and worked on 3 main domains : room acoustics, environmental acoustics and building acoustics, in which modelling approaches and calculation tools have been developed.

Work was mainly supported financially by the government (more than 60% of its budget at the beginning).

From the start, CSTB has been involved in standardization at French, European and International levels. The CSTB new European laboratory, LABE, built in the late 90s, proposed a new and faster way to test building components. Since, the government financial contribution has decreased (from more than 60% to less than 20% of CSTB budget), and furthermore, due to the increased awareness of climate change, the thermal and energy related aspects for buildings have become dominant, shading acoustic research activities.

Keywords: *building acoustics, environmental acoustics, room acoustics, modelling, measurements, research center.*

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1. THE BEGINNING

The Center for Building Science and Technology (CSTB) was created in Paris in 1947 to bring together construction specialists in order to draft building rules after the second world war. Jacques Brillouin, French acoustician [1], expresses the need to collect acoustic measurements in buildings and establishes a measurement team within CSTB.

In 1957, the CSTB, headed by Gérard Blachère, decides to bring science into construction, and an acoustic division is created, headed by Robert Josse, a telecommunication engineer, associated with a human sciences division. The goal is to develop acoustic comfort rules, validated by the social sciences, predictable by calculation and controllable by measurements. The first rules regarding sound insulation in buildings are instituted.

1.1 National activities

In 1962, R. Josse publishes his first (small) book on building acoustics [2], followed by a second one [3], more developed, dealing particularly with environmental acoustics and building acoustics. These books are mainly dedicated to common building. R. Josse also publishes scientific work on sound transmission through walls [4].

An acoustic performance evaluation laboratory for walls, floors and windows is built in Champs sur Marne (Paris area) while the acoustic team grows. A new laboratory method for characterizing facets is then developed, standardized first in France and later at international level. Later on, a temporary building present in Champ sur Marne enabled the study of the effect of the angle of incidence on the sound insulation of different glazings and the effect of balconies.

In the mid-60s, CSTB obtained financial support for major development. New acoustic laboratories are built in

Champs sur Marne, and a computing center is also created. The development plan involved a research effort with new resources in personnel and equipment, a link with universities and the development of models, either scale models or calculation models based on physics (see Section 2).

The interest in environmental noise corresponds to a global concern linked to the rapid development of transport infrastructure and the associated traffic. A 1/20° scale model chamber is then built at CSTB to study environmental sound propagation and the effects of screens, where cat bells are used as sound sources to simulate the 500 and 1000 Hz octave bands on a scale model. The scale model chamber was equipped with a motorized mast for microphone automatic movement, air absorption corrections were taken into account on the basis of temperature and humidity readings. A large collection of propagation abacus and traffic power laws were created to constitute a forecasting method while a theoretical work exploited the results for a numerical model. That same year, a vast traffic noise measurement campaign [5] was undertaken in Paris and its suburbs (more than a hundred locations). Measurements were performed 2 m from the building façades (see Figure 1) during 48 hours, the sound levels being recorded in 5 dB increments on statistical counters and collected hour by hour on silver film to be converted into punched cards processed at the CSTB computer center. Traffic counts were associated with each measurement.

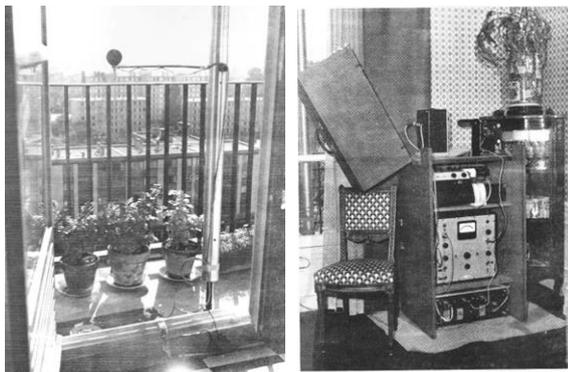


Figure 1. Traffic noise measurements.

The associated sociological survey covered a sample of 500 people living near the measurement points. The study led to annoyance versus road noise curves. The knowledge of road traffic noise was complemented by that of railway noise. The measurements in open terrain used masts 30 m high and simultaneous recordings on prototype tape recorders. A photographic system made it

possible to assess the speed, type and length of the trains [6].

The experience of traffic noise measurement campaigns associated with sociological surveys led CSTB to subsequently participate in the standardization of a European questionnaire. The L_{Aeq} index was again validated against noise annoyance with an excellent correlation.

1.2 International activities

International activities were developed early by Gerard Blachère who created the “Conseil international du bâtiment” (CIB), bringing together the research centers of the main European countries, North America, Brazil and the USSR. This council defines common research themes and exchanges between laboratories.

R. Josse then leads an important action at the international level to develop measurement methods and define acoustic descriptors and the associated vocabulary. Supported by sociological surveys, he pled for generalizing the dB(A) use in regulations with limits associated to a single number quantity. In 1968, a congress bringing together all the acoustic laboratories working within the CIB was organized in Paris under the chairmanship of R. Josse. Two major subjects of the time were on the agenda: outdoor noise and floor impact sound.

- The importance and topicality of the outdoor noise subject were recognized. Results from the CSTB Paris demonstrated the validity of the L_{10} (level reached and exceeded 10 percent of the time), which was adopted in England by the BRE. Judith Lang (Austria) presented the results of a Vienna survey validating a new index: the equivalent sound level, which was then used by CSTB in its own measuring campaigns and validated.

- The work presented on impact noise included research work on a reference source: a walking shoe for France (see Figure 2) [7] and a tapping machine for Germany and the Netherlands, which was used afterwards at CSTB to develop the impact sound evaluation method and related descriptors. Note that the first description of a tapping machine was already included in 1938 in DIN 4110.

1.3 Concorde sonic boom investigations

In 1969, Concorde aircraft flights were launched with the hope of exploiting it at supersonic speed above inhabited zones. Many studies were then initiated to estimate the reactions of the populations flown over, to the sonic bang emitted throughout its trajectory, as well as to evaluate the possible disorders and damages on light constructions and

old heritage buildings.

CSTB was requested to study these potential disorders and damages both theoretically, by estimating the overpressures generated inside the buildings, and experimentally by in situ measurements. Later on (see section 2), measurements on structural elements were performed in laboratory.

An experimental house was built in Istres (close to Marseille) and subjected to Mystère IV military jets passages at different altitudes in supersonic flight (see Figure 3). The last tests were carried out with flights at 600 m altitude, planned to be destructive, which was actually verified. Furthermore, cathedral stained glass windows were subjected to supersonic flights of military jets were equipped with vibration sensors. A paper synthesized the different investigations carried out on this subject [8].

The overflight of inhabited areas at supersonic speed was then prohibited.

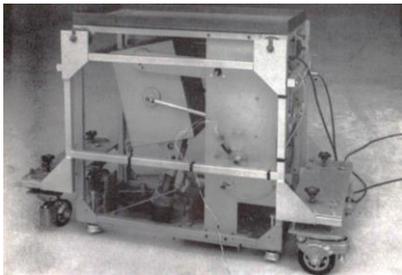


Figure 2. CSTB walking machine.



Figure 3. Experimental house subjected to aircraft passages in supersonic flight.

2. DEVELOPMENT

In 1970, Robert Josse accompanied by 6 other acousticians moved to Grenoble; the team quickly increased by 4 more persons. The acoustic division became the acoustic department, the testing laboratories still being in Champs sur Marne and three other divisions were created in Grenoble, mainly for applied research in the three domains: building acoustics, environmental acoustics and room

acoustics. New acoustic laboratories were constructed on the Grenoble site in 1973, mainly for research. All this corresponded to the CSTB research effort in developing models, either calculation models based on physics and/or scale models, which also allowed validating calculation models.

2.1 Environmental acoustics

2.1.1 Metrology

The first test facilities build in Grenoble was a lightweight ceiling fatigue test bench, build to study the potential damages of sonic booms, using a huge piston to produce the necessary overpressure impulse (see section 1.3).

2.1.2 Scale modelling

Since the 1/20 scale model had been validated with the construction of the first sound barrier, a 1/100 scale model, suitable for urban planning, was considered technically possible on the condition of working in dehydrated air (3% humidity at 20°) in order to compensate for the growth of conventional absorption by reducing molecular absorption. Suitable microphones (1/8" inch) were not very sensitive and required powerful sources. Sources based on air jets were developed. Inaugurated in 1975, the “maquette” laboratory (see Figure 4, [9]), equipped with significant automation, was quickly monopolized by major transport infrastructure projects.

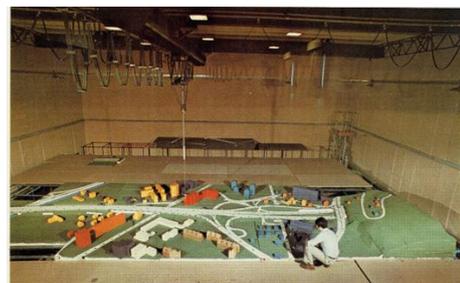


Figure 4. the “Maquette” laboratory for environmental noise evaluation.

It should be noted that the West German Ministry of the Environment launched then a project to compare prediction methods and in situ measurements. The predictions by the CSTB scale model were validated, which subsequently led to work on German infrastructure projects.

2.1.3 Calculation models

At the same time, prediction algorithms [10] based on ray tracing, precursor of noise mapping current tools, were

developed, a constant comparison between in situ measurements, scale-modeling and calculation models allowing a permanent improvement of the calculation models (see Figure 5). This work led to an acoustic simulation software based on a GIS, MithraSIG, co-developed by CSTB and GEOMOD.

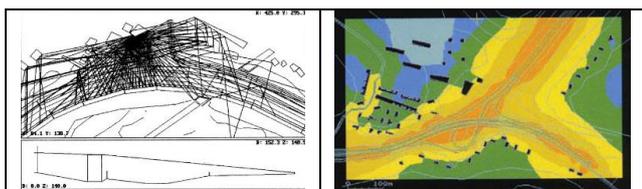


Figure 5. Ray tracing tool toward noise mapping.

An extension of the ray tracing approach was dedicated to electromagnetism ; MithraREM software co-developed by CSTB allows simulating at city scale electromagnetic fields of antennas (mobile, telephony, radio, TV...).

Furthermore, the ray acoustic solver ICARE from CSTB is integrated to Siemens Simcenter simulation and testing solutions. ICARE allows simulation of acoustic propagation in complex 3D environments.

2.1.4 Use of finite/boundary element models

The optimization of road screens required in the 90s the fine modeling of diffraction phenomena using boundary elements [11]. A software has been developed internally (MICADO software). This approach allowed in particular the study of screens at the edge of railway tracks taking into account the acoustic interaction of the train with the screen (Figure 6).

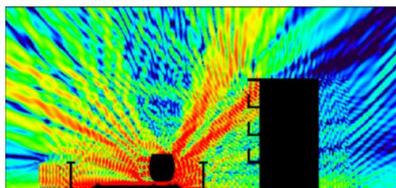


Figure 6. Acoustic field generated near a building by a railway track with screen.

2.1.5 Creation of “ACOUSTB” subsidiary in 1995

A significant number of operational studies were performed not only at the CSTB “maquette” laboratory, but also using the CSTB ray tracing calculation model, first used by CSTB only, but then marketed (MITHRA software) and used by other consultant companies. The contribution of operational work in order to feed research work was found essential but

led to two difficulties within CSTB structure: (i) the urgency associated with operational studies required skills from research teams disorganizing them; (ii), the suspicion of using research funds to make attractive commercial offers existed.

For this reason, the CSTB management decided in 1995 to create a private acoustic subsidiary, with about fifteen persons including part of the staff of the CSTB acoustics team. The ACOUSTB subsidiary was established in partnership with a large engineering company in transport infrastructure. The synergy between research and operational investigations was then preserved through scientific assistance contracts.

Furthermore, in the late 80s, spin-off acoustic firms were started by some of CSTB personnel.

2.2 Building acoustics

From the 1970s, CSTB decided to develop the modeling of acoustic and vibration phenomena (scale-models and calculation models) in order to understand and predict the acoustic performance of the building and its components. Different approaches, described below, have been studied and used. Some approaches and models have been the subject of PhD work supervised by different universities.

2.2.1 The SEA contribution

This method, developed in the early 1970s by Richard Lyon, USA MIT, makes it possible to estimate the sound and vibration energy of rooms and structural elements (walls, beams ...) in broadband (1/3 octave or octave), for a given sound or vibration excitation. At first simple, this method requires a good physical knowledge of the couplings between structural elements or between structures and rooms, and was only mastered at the end of the 90s.

CSTB adopted the method and worked for many years to develop it; an operational software (CATRAS software) was developed in the mid-1980s, taking into account the different types of waves in structures [12]. CATRAS has been used for studying the propagation of structural noise in assemblies of structures (see Figure 7), and in particular in a Parisian project where the railway tracks near Gare d'Austerlitz were covered with residential and office buildings (late 90s).

CATRAS was also used for the French Navy: (i) in the mid-1980s, in a study of the propagation of impact noise generated by aircraft catapults in the structure of aircraft carriers, with experimental validation on the aircraft carrier Foch, then (ii) at the end of the 1980s, in a study of the structural noise generated by a heel compensation system (by mass displacement) of an aircraft carrier (see Figure 8).

The financial support brought by the contracts with the French Navy contributed to more R&D in the domain of structure-borne sound transmission.

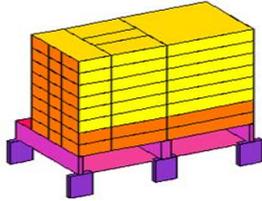


Figure 7. Building and covering structure for railway tracks (Parisian ATM project).

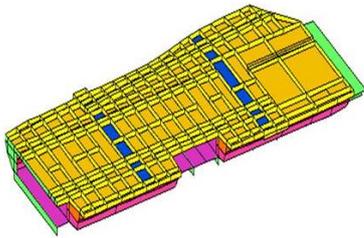


Figure 8. Example of modeled aircraft carrier structure.

2.2.2 European standardization (of SEA in particular)

In 1985, a new approach was formulated to support the CE marking of products and allow their free circulation in the different European union countries. The method consisted of drafting essential requirements in the form of directives to be transposed into national law, while the technical specifications used to meet these requirements refer to harmonized European standards prepared by a European Committee for Standardization (CEN). The chairmanship of the building acoustic technical committee CEN/TC126 was attributed to France, and with one exception, ensured by CSTB.

Among the work of this commission, it should be mentioned the definition of single number quantities which gave rise to memorable clashes between the French approach and the German tradition, ending with the adoption of a complicated index.

The SEA model, simplified in the early 1980s (TNO [13]) in its building application and reduced to transmissions between neighboring rooms was discussed within CEN TC126 from the 90s with the active participation of CSTB and led to the EN 12354 series for predicting building acoustic performance from the building components. This standard series shows that working together at European level has been very fruitful. Recent revisions take into

account low frequencies (down to 50 Hz), lightweight structures and structural noise sources (building service equipment).

The above European standards have been progressively implemented at CSTB in the ACOUBAT software (see Figure 9); in France, the ACOUBAT distribution reached about 400 licenses in the 2000s. It should be noted that the ACOUBAT software was also sold in Spain and used, once a specific database of Spanish building products was created in the software.

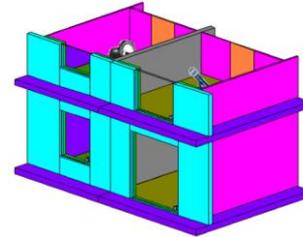


Figure 9. Example of horizontal noise transmission configuration between rooms (ACOUBAT software).

2.2.3 CSTB design tools and solutions for the French acoustic regulation in 1995

The French acoustic regulations concerning new housing dated from June 1969. The progress made in construction materials and techniques, in particular the use of lightweight structures and thermal insulation, required both setting the level of new requirements and review the design guides to achieve them. In this context, CSTB played the role of technical support for the ministry concerned, in the dialogue between manufacturers of construction products, social construction organizations, and the demand for quality by the inhabitants.

Appropriate design tools had been developed in the 80s and made available, such as the ACOUBAT software (see above). ACOUBAT was used for the acoustic predictions, which contributed to the development of examples of acoustic solutions (ESA) satisfying the 1995 French acoustic regulations. The document presents building configurations for each regulatory section (for example impact noise) using products belonging to performance classes (Figure 10).

2.2.4 Modelling multilayered building elements

The increasingly frequent use of double-glazing, double-walls and light multi-layer walls required, for their optimization, the development of multi-layer physical models at the beginning of the 90s, first with the modal approach, quite heavy, then with a simpler wave approach:

the calculations are carried out wave by wave, for a given frequency, in the wavenumber domain and the method is applied to layers of infinite surface, the finite dimension effects of the element being approximated by rectangular spatial windowing of the acoustic waves radiated on the reception side [14]. Originally developed to model the performance of elements in airborne transmission, the wave approach was then extended to impact noise transmission performance in the early 2000s [15]. The calculation software was marketed in 2010 (ACOUSYS software).

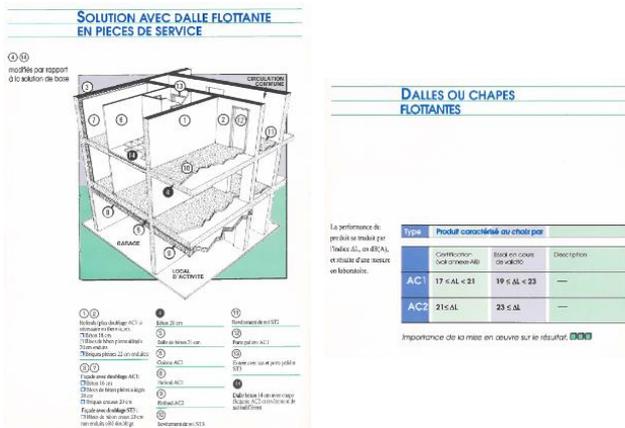


Figure 10. Examples of Acoustic Solutions (1995): solution with floating slab in service rooms and associated classes.

2.2.5 Finite element (FEM / BEM) contribution

In the 90s, the need to know the vibrational soil-structure interaction (at the level of building foundations in particular) to study and predict the transmission of railway vibrations from the ground to buildings, led to the development of a numerical model. [16]. First in 2D, the model was developed in 2.5 D (structures infinite in one direction), thus lighter than in 3D and well suited to line sources [17]. This software makes it possible to obtain maps of vibratory fields (Figure 11). The software was marketed in the mid-2000s (MEFISSTO software).

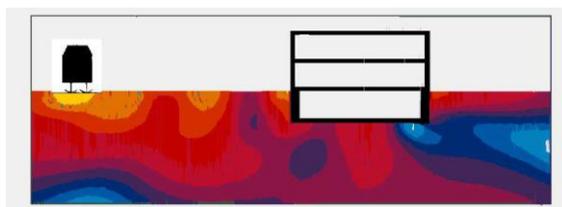


Figure 11. Ground vibration levels by trains.

2.2.6 Metrology

In the 70s, CSTB worked on developing a new method for sound insulation measurements [18]; the method was based on using pistol shots as the sound source, and had the advantages of speed and economy in comparison with classical measurements.

Like many European centers, CSTB gained knowledge on acoustic intensity during the 1980s and used this technique in particular in building acoustics [19]. A few years later, CSTB became interested in acoustic imaging and acoustic holography [20], a technique allowing the visualization not only of the acoustic field emitted by a wall but also of the vibratory field of this wall and the resulting sound power. A measuring testing bench was built on the Grenoble site (Figure 12). The decomposition of the sound field into plane waves for a given frequency makes it possible to visualize the isotropy (or orthotropy) of building walls.

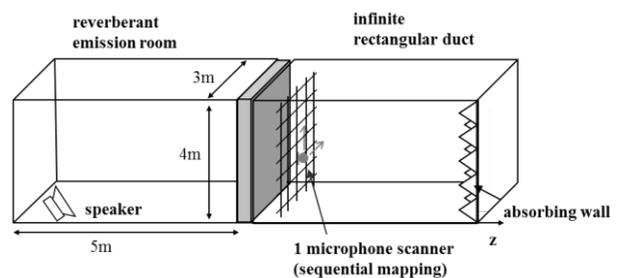


Figure 12. Acoustic holography test bench built at CSTB.

2.3 Room acoustics

The skills acquired at CSTB regarding scale models as well as computer modeling found an outcome in room acoustics. One of the most prestigious applications was undoubtedly the design of the great hall of the Opéra Bastille (architect Carlos Ott, acoustic design Helmut Müller, Müller BBM and Jean Paul Vian CSTB). A 1/20 scale model made it possible to draw the geometry of the hall to meet the request of a “popular” opera house where each of the 2700 seats had to have good acoustics (see Figure 13).

The ICARE software, successor of CSTB Epidaure software [21] based on ray tracing has been used for the study of the acoustics of the Beijing Opera (Architect Paul Andreu, with J.-P. Vian from CSTB as the acoustician at the start of the project). In order to satisfy both the architect and the acoustician, the visual shape of the room and its acoustic geometry have been decoupled by the use of a metallic mesh curtain, opaque for the eyes but transparent to the acoustic waves.



Figure 13. CSTB scale model of Opéra Bastille.

In the 90s, the CSTB acousticians were also concerned with improving the natural acoustics of concert halls without requiring any architectural modifications (materials or geometry). They developed the electroacoustic “Carmen” system to control the reverberation time. Consisting of active cells composed of a microphone and a loudspeaker, and hidden in the room’s walls and ceiling, sound is captured and replicated in real time, as if naturally reflected by the walls [22]. The Carmen system has been installed in several concert halls in France and abroad.

2.4 Commissioning of a large innovative acoustic measurement laboratory in Champs sur Marne

In the 1990s, the demand from manufacturers to test construction elements grew rapidly due to the emergence of new products: lightweight structures, thermal-acoustic insulation, floor coverings on a resilient underlay, windows intended for noisy areas... A new laboratory was therefore designed and built to meet this demand. One of the problems encountered by traditional laboratories is that the construction of the tested element, and the drying in the case of concrete elements, for example, neutralizes a test station for a period which can go up to one month, seriously limiting the number of tests that can be carried out. Hence, the idea of designing transmission test chambers with a fixed noise reception room and a mobile noise emission room that can move apart to make space for a frame in which the tested element had been previously built in a different laboratory zone. This laboratory, called “Laboratoire Acoustique du Bâtiment Européen”, LABE, which was inaugurated in July 1998, has six testing stations, three of which are equipped with mobile rooms, one dedicated to lateral transmissions, a reverberation room for sound absorption and acoustic power measurements as well as a station dedicated to measuring the hydraulic components (see Figure 14). More than a thousand tests are carried out each year on building elements.



Figure 14. CSTB acoustic laboratory, LABE.

3. NOWADAYS

Concerning environmental acoustics, CSTB has participated to important European projects, Harmonoise and Imagine, that allowed improved methods for noise assessment in the environment. Finally, a common framework for noise assessment methods (CNOSSOS-EU) from the main sources of noise (road traffic, railway traffic, aircraft and industrial), was developed to be applied for strategic noise mapping. In 2020, CSTB proposed improvements to the 2012 CNOSSOS-EU method; this new method was integrated into the modification of the Annex II of the European Directive which was adopted in December 2020, becoming the official method starting in 2021; it has been integrated in the MithraSIG software. Furthermore, much work has been dedicated to sound models simulating urban noise through auralization (MithraSound software). Indeed, such tools are essential for assessing the sound impact of a development project by listening to a simulation. Concerning buildings acoustics, lightweight buildings have been a major subject in the past two decades, at the French and European level, especially due to promotion of carbon storing renewable materials. The use of biobased and geobased materials in buildings has also been investigated. CSTB also remains dedicated to improve and optimize products for industrial partners, in terms of acoustics but also with a broader analysis. Indeed, multidisciplinary projects have become more and more common, such as coupling acoustic and thermal renovation, global comfort approach, etc...The CSTB participation in the RIVAS European project allowed more activities in railway induced vibration and structure-borne noise in buildings, subject of a soon coming regulation in France.

Concerning room acoustics, a new system dedicated to the acoustic variability of small and medium-sized venues has been developed : CarmenCita.

The acoustic activities still continue, in spite of limited government financial contribution compared to the 70s, also related to the now dominant concerns about thermal and energy related problems in buildings. CSTB has been switching towards research partnerships with major focus for developing and supporting innovation and improving usability, while tackling the socio-economic challenges of safety, health and comfort and the environment and energy, as they apply to buildings, neighborhoods, and cities.

4. ACKNOWLEDGMENTS

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HISTORY AND ACTIVITIES OF KU LEUVEN LABORATORY OF ACOUSTICS

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ABSTRACT*

The Laboratory of Acoustics at KU Leuven was founded more than 50 years ago. Till today, a variety of acoustics related topics, ranging from physical acoustics, through building and room acoustics up to environmental acoustics and noise related health issues, has been investigated. In the second half of the 20th century, the laboratory was one of the main centers of expertise in acoustics in Belgium, which contributed to consulting and the establishment of legislation in building and environmental acoustics. In the 1990's it also consolidated expertise on the characterization of porous materials and was one of the driving research groups in the field of photoacoustics.

During the past 15 years, additional research directions have been taken thanks to interdisciplinary collaborations, including psychoacoustics, perception of sound, sound quality assessment, archaeo-acoustics, tackling acoustic issues in building retrofit, and characterisation of walls materials in the framework of sustainable development (recycled materials, biomaterials etc.)

This paper first brings a brief historical overview of activities of ATF performed in the past, its involvement in national and international collaborations and its main recent scientific and educational activities.

Keywords: *Physical acoustics, Building and Room Acoustics, Noise control, Psychoacoustics.*

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1. EARLY HISTORY OF THE LABORATORY OF ACOUSTICS

The Laboratory of Acoustics has its roots in the Faculty of Sciences of the Catholic University of Leuven (1425-) and the initiative of physics professor Augustin Van Itterbeek (1904-1968), who was leading the Laboratory of Low Temperatures and Technical Physics. The latter had been appointed in 1932 to organize a physics research laboratory for Dutch-speaking students as part of the university's Flemishization. Van Itterbeek initiated a program “ingénieur-physicien” in 1936. Graduated engineers there could receive additional training in scientific research. The program also opened paths to industry for the physicists themselves. In that context, physics research was organized into groups around low temperatures, viscosity, acoustics and nuclear physics. After the university was split in 1968, the Department of Physics was created with seven divisions, including the Acoustics and Thermal Conductivity (“Laboratorium voor Akoestiek en Warmtegeleiding (AW)”) division, which was initially led by Prof. Odiel Van Paemel (1911-2006). The other pioneering laboratory members were Prof. Henri Myncke (1921-2001), Prof. André Cops, Paul Jacques and Willy Delvaux. The research part of the department relocated to new built facilities on the Heverlee campus in March 1972 (Fig.1 and 2).

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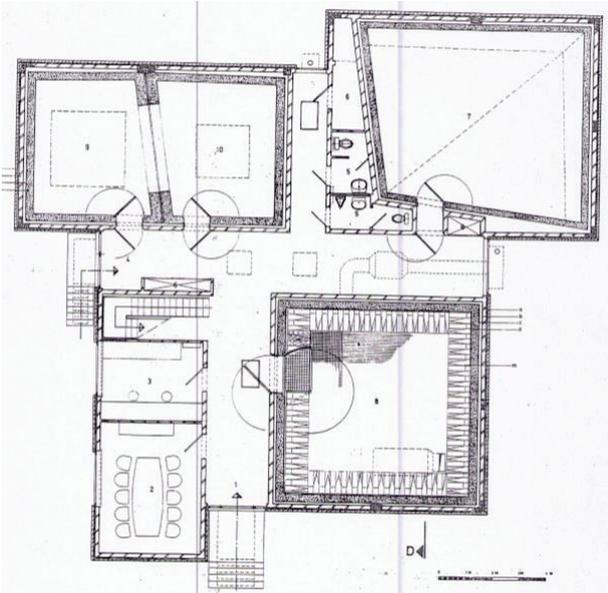


Figure 1. Ground plan of the laboratory (1967)

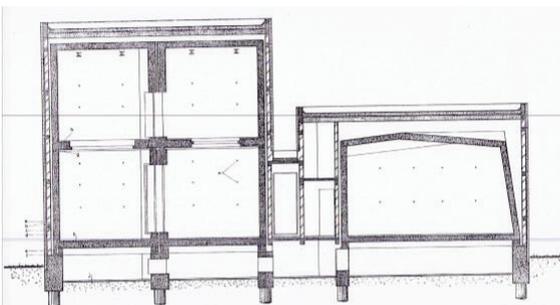


Figure 2. Cross-section of the laboratory, transmission rooms and reverberant room (1967)

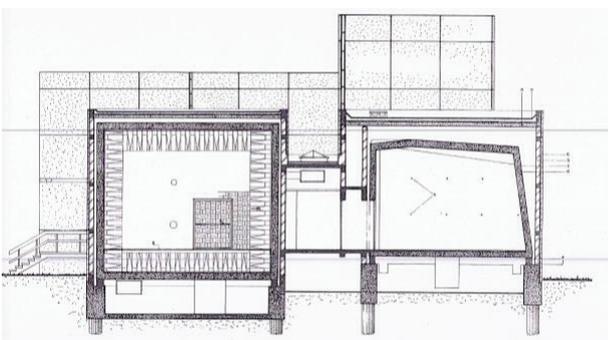


Figure 3. Cross-section of the laboratory, anechoic and reverberant room (1967)

The new acoustics laboratory building, which included an anechoic room, a reverberation room and sound transmission rooms, had already been occupied by then. The acoustic facilities (all built in a robust “box-in-box” approach) as well as setups for determination of thermal conductivity were used for developing measurement methods and performing service measurements for companies.

Among the first environmental acoustics activities were traffic noise measurements (near the newly built E40 highway between Brussels and Liège and near Antwerp), and evaluations of noise disturbance (on the instructions of the Belgian Ministry of Public Health). This venture was undertaken with the help with newly hired members Piet Steenackers, Willy Bruyninckx (1949-2022) and Roger Gambart. In 1986, Prof. Jan Thoen joined the laboratory and became its director in 1988. The laboratory further developed its expertise in building acoustics, room acoustics and environmental acoustics, in particular in many studies and consulting on airport noise. In 1987, Prof. Jan Thoen started also research on photoacoustic and photothermal phenomena. Later on, the expertise was (in collaboration with Prof. Jan Wouters and Prof. Astrid Van Wieringen from audiology department) extended to the-perception acoustics. Around 2000, after a significant expansion of the lab building, the group of Prof. Gerrit Vermeir joined on the building-related acoustic topics throughout the years, several members of the laboratory have taken leading roles in different national and international societies related to acoustics. In particular, Prof. André Cops and Prof. Gerrit Vermeir have chaired the Belgian Acoustical Society (ABAV) and the former one has also been Secretary-General of International Institute of Noise Control Engineering (INCE). In the early 1990s Prof. Jan Thoen served as Secretary General of the Federation of Acoustical Societies of Europe (FASE). Prof. Monika Rychtarikova has chaired the Technical Committee of EAA Room and Building Acoustics (2011-2017). The evolution of the different research, education, dissemination, and consulting activities is sketched in the following thematical overview.

2. THEMATIC OVERVIEW

2.1 Environmental acoustics

Acoustics is one of the scientific disciplines that is connecting research in physics with society. Along with the industrial evolution, the population density growth and the increase of motorized road, railway and airborne traffic, concerns about the impact of noise on health have led to the need for expertise on efficient noise abatement. In view of this, from its early days, the laboratory has been very active

in noise mapping, consultation for developing measures for mitigating noise problems, and developing adequate legislation. Since the foundation of the laboratory, Belgian (Ministry of Public Health) and later on Flemish governmental administrations (subsequently the Administration of Spatial Planning and Environment – AROL, the Administration for Management of Environment, Nature, Land and Water – AMINAL [1] and the Department of Environment, Nature and Energy – LNE [2]) have been consulting its experts (Prof. Henri Myncke and Prof. André Cops, Willy Bruyninckx, Paul Jacques and Prof. Jan Thoen) for advice in general and compiling texts that currently still make part of the Flemish Regulation concerning the Environmental Permit (VLAREM [3]). Essential points of noise regulations, target $L_{A,eq}$ values (“richtwaarden”) and limits and permits to install noise producing facilities in Flanders is that these are determined by zones [4], and take into account the original sound $L_{A,95}$ -levels. In this context the laboratory executed and coordinated many studies on environmental noise impact for industrial partners and several pilot studies for the Flemish Government (e.g. PESO (1993) and EVA-PESO (1995) on evaluation methods for nature quiet areas; EMOLA (1997) on the determination of emission levels to the environment). From the beginning of the 1990s significant contributions were made on the determination and evaluation of aviation noise near the airport of Brussels for RLW (Regie der Luchtwezen) of the Belgian Government and for the Brussels Airport Authority, e.g. in 1989, 1990 and 2014: on noise from airplanes on the ground, from 1997 onwards: scientific support for noise control measures, from 1996 to 2014: calculation and evaluation of noise impact contours. The laboratory made a report on the environmental impact of Brussels Airport (MER-geluid Zaventem 2000). Similar MER reports and noise contour evaluations were also executed (from 1997 to 2022) for three regional airports (Oostende, Antwerpen and Kortrijk-Wevelgem) in Flanders. Throughout the years, also support for noise control measures near the race track of Zolder, motorcross circuits [5] and wind turbines [6] was supplied by ATF.

Via partnership in the European projects ADRIENNE [7] and QUIESST [9], the laboratory has also contributed to the development of European standards for measuring procedures CEN 1793-2 and CEN 1793-5 and 6 for the *in situ* determination of the absorption and isolation of noise barriers [10].

Further in the field of environmental acoustics, together with the Building Physics group (BP) at KU Leuven Department of Civil Engineering, ATF contributed with a new approach to classify soundscapes in the framework of the Belgian project DRUPSSUC [11,12].

2.2 Building acoustics

Where in the early years’ attention was focused on the use of the tube method, measurement techniques and in-situ measurements, the facilities of the newly installed laboratory opened many new avenues [13]. From 1969 there was the possibility to make use of transmission rooms, an anechoic room, and a reverberation room. Commissioned work and research clearly got off to a rapid start with reviewed published work. First on a study on sound field diffusivity in the reverberation chamber [14], work on a sound reflection set-up in the anechoic chamber [15] and work on sound transmission. [17].

The nature of the research topics, in particular the properties of building materials and constructions, was also very appropriate within the architectural engineering program of the Faculty of Engineering Sciences. This laid foundations for a solid collaboration on a study of noise transmission in buildings and the use of statistical energy analysis (SEA) [17] which triggered the start of frequent interfaculty master’s and PhD work. Different parts of the laboratory infrastructure were used for dedicated goals.

The **transmission chambers** were intensively used for the standardized determination of the airborne sound insulation of walls, floors and later also roof constructions, and for the standardized impact noise testing of floor constructions. Time remained available for in-depth examination and experimental work into sound radiation measurement techniques. Attention was given to the then-new sound intensity measurement technique and research related to the standardization. Also, the sound isolation quality of separation walls, sound propagation by flanking paths, internal damping of walls and floors were highlighted. Recently, a new step was made in the measurement of acoustic sound isolation by using a laser Doppler vibrometer to measure the vibration of a wall of interest and extracting from the deflection shape the sound transmission and isolation spectrum. This method, which was consolidated in the framework of an EU RISE project PAPABUILD [18], has been validated with the classical microphone-based approach for intermediate frequencies. Its main strength is to yield reliable data in the low-frequency range, where the microphone-based method becomes unreliable due to the non-uniformity of the sound pressure level in the measurement rooms, caused by standing wave modes [18-19]. An advanced computational approach of ribbed and stud frame assemblies [20] was successfully compared to laboratory experiments in the work of the team of Prof. Edwin Reynders, successor to Prof. Gerrit Vermeir.

The laboratory also holds a **concrete scale set-up used in the study of flanking transmission [21]** and later converted into a holographic set-up.

2.3 Room acoustics

Research in room acoustic topics has been ongoing in the laboratory since many years, coordinated by Prof. Gerrit Vermeir. In the end of the 20th century, the group belonged to one of the European leaders in this field. In house developed software EPIKUL was one of the leading ray-based software of those times [22]. The group was involved in many projects (both research-wise and consulting-wise), including several in very interesting locations, such as: BOZAR concert hall (Brussels PDS aula (Leuven) [23]. Among the large number of smaller projects and so called second opinion activities, some of the noteworthy are the Elzenveld chapel in Antwerp, AMUZ (Antwerpen), Scheepvaart museum Amsterdam, several projects in Westmalle (Trappistencafé, bbeey church, new brewery bottling plant).

Within the laboratory facilities, the reverberation room has been intensively used for standardized sound absorption testing. In the context of ISO standardisation, the laboratory participated in several round-robin tests. The determination of the sound power of various (ventilation) equipment for buildings was also addressed. In terms of research, the influence of edge effects of samples, the diffusivity of the sound field, and the validation of modeling scattering [24] were discussed throughout the history.



Figure 4. Building of the Laboratory of Acoustics (Photo Peter Hanuliak)

In the **anechoic room**, important steps were taken in the measurement techniques concerning reflection, absorption, and diffusion of sound: burst tests [25], over impedance tests [26] to scanning tests [27]. In the reverberation room tests concerning the diffusivity of the sound field, over numerous

standardized sound absorption measurements, to set-up and developments on measurement techniques related to the sound reflections. [28]

Recently, room acoustic research has increasingly focused on interdisciplinary collaborations, mainly with KU Leuven research groups in architecture and in audiology. Joint research with experts in architectural history [29] has led to a recently approved ERC Pathfinder project between Oxford University (Prof. Küge) and KU Leuven (Prof. Rychtáriková and Prof. De Jonge). The infrastructure (anechoic room) is being extensively used for the preparation of anechoic recordings for high-level binaural auralisation and for listening test experiments free of background noise and reverberation.

2.4 Psychoacoustics and sound perception

In collaboration with BP - KU Leuven and the KU Leuven laboratory for Experimental Oto-, Rhino-, Laryngology (expORL), the laboratory has put its first steps into the field of psychoacoustics and research on perception of sound in the framework of an FWO-V project (“VIRTAK”) on sound source localization, the use of virtual acoustics for testing of speech intelligibility of hearing impaired people [30,31] and echolocation [32,33], by combining binaural impulse response simulations with listening tests with auralized sound. This research was further extended to auralized sound-based recognition of textures of walls. The group also performed listening test-based assessments of wall sound isolation performance in the framework of finding an optimum single number quantity (SNQ) that takes into account the frequency dependence of human hearing. This research was complemented by a proposal for a Loudness calculation-based assessment method of the adequacy of SNQs for sound isolation, which was validated by listening test-based results.

2.5 Physical acoustics

Along with the measurement and evaluation of noise in the living environment, developing and characterizing materials for optimum absorption, isolation or scattering performance in applications, has made an important part of the activities in ATF. In close collaboration with international partners at the universities of Le Mans, Hull, Trondheim, Nevers and others, ATF contributed to the development of dedicated measurement techniques for the key physical parameters that determine the acoustic absorption of porous materials, i.e. the tortuosity, the porosity, the flow resistivity, the thermal characteristic length and the viscous characteristic length [34], and for the macroscopic determination of the sound

reflection. This main driving force behind this research was Prof. Walter Lauriks (1961-2010), in close collaboration with Prof. Jean-Francois Allard and colleagues from Université du Maine (LAUM), France.

Around 1987, a new research direction was opened by Prof. Jan Thoen in the emerging field of photoacoustics, which makes use of the phenomenon where intensity modulated light absorbed by a gas, liquid or solid, through thermal expansion, results in density variations that in turn correspond with sound or ultrasound. This phenomenon was first discovered by Alexander Graham Bell and his assistant Sumner Tainter, and along with the emergence of laser technology, made its way into material science after a publication [35] by Allan Rosencwaig and Allen Gersho in 1980. This approach allows to get combined information on optical absorption properties, thermal properties and mechanical properties of materials and became a unique tool thanks to the versatility of laser light in terms of allowing to generate arbitrary spatial and temporal excitation patterns and remotely detect the resulting thermal expansion and acoustic waves. ATF made substantial contributions to this research field, and was an active player in different European projects. In 1994-95, Prof. Jan Thoen coordinated a large EU Human Capital and Mobility project on “Advanced materials characterization by photoacoustic and photothermal phenomena”. Initially research efforts concentrated on thermal properties near phase transitions [36-38] but soon extended to depth profiling [37,38] and acoustic wave generation and detection, in particular in applications of depth profiling [39-43] (EU project HARDPHOTOTEC, grant no. BRRT-CT-5032), non-destructive testing by laser ultrasonics [44-47] (EU-ITN project NDTonAIR [48]). Recently the first footsteps were made in the field of elastic characterization of biological cells and tissue, and photoacoustic imaging [49,50], in a perspective of using this approach for biomedical applications.

A nice synergy between physics and arts was evidenced by the outcome of a collaboration between the laboratory and artist Aernoudt Jacobs, in the form of the artworks “Photophone” [51] and “Heliophone” [51,52], in the framework of an IWT CICI-grant (2013-2015).

The multidisciplinary nature of the laboratory is well reflected in the ongoing EU-MSCA doctoral network, Acoustic and Thermal Retrofit of Office Building Stock in EU (ACTAREBUILD) [53], which joins efforts in sustainable development and thermal and acoustic characterisation of green and recycled materials, with special attention to the acoustic perceptible importance of innovative measures in building physics, while training young researchers. Education¹

2.6 Flanders

In Flanders, members of ATF has contributed to different courses on acoustics listed below:

- Fundamentals of Acoustics (AC, WL, CG), Building Acoustics (GV, AD, ER), Measurement techniques and signal processing (BR) (Hogere Cursus Akoestiek, IENET)
- UIPOUUY Advanced Acoustics (Master of Physics, KU Leuven: 1987-2021) (JT, WL)
- Environmental Acoustics (Master Environmental Studies, KU Leuven: 1987-2010) (JT, WL)
- Control technique: sound (Environmental coordinator, Syntra West (-2020) (WB, CG)
- Waves and sound (Bachelor Logopedy and Audiology, KU Leuven)
- Introduction to the Physics of Speech and Hearing: Waves and Sound (Bachelor Logopedy and Audiology, KU Leuven)(CG, JW, MM)
- Noise control (Master of Bioscience Engineering: Human Health Engineering, Master Building Engineering, KU Leuven (GV, ER)
- Building acoustics (Master Building Engineering, KU Leuven) (GV, ER)
- Room acoustics and lighting (Master Building Engineering, KU Leuven) (GV, ER)
- ERPhysics: additional topics: sound (Bachelor Architectural Engineering, KU Leuven)(CG),
- Comfort: acoustics (Bachelor Architecture, KU Leuven)(MR)

2.7 International level

At international level, ATF has been a collaborator of several EU educational projects, networks and platforms [44], among which the most recent were Erasmus projects (Lifelong Learning Programme)

- Acoustics for Architects (ARAC platform) <https://arac-multibook.com/>, Programme: Leonardo da Vinci Transfer of Innovation. No. 2013-1-PL1-LEO05-37588. (2013-2015).
- Acoustics for Engineers (ACE) <https://ace.acoucou.org/> Programme: ERASMUS+ Strategic Partnerships for vocational education and training. No. 2016-1-PL01-KA202-026719. 2016-2018)
- Acoustics for Industry (ACI) <https://aci.acoucou.org/>. ERASMUS+ Strategic Partnerships for vocational education and training; No. 2017-1-PL01-KA202-038577. (2017-2019) [54]
- Acoustics Knowledge Alliance (ASKNOW) <https://asknow.acoucou.org/>. ERASMUS+ Knowledge

Alliances All the activities within the Acoustics Knowledge Alliance (ASKNOW). No. 612425-EPP-1-2019-1-FR-EPPKA2-KA) (2020-2023).

3. DISSEMINATION

Collaborators of ATF has organized or co-organized a high number of national and international events, seminars or conferences. The most important are:

3.1 Conferences

- Chair of Internoise 1981 Amsterdam (AC)
- Chair and proceedings editor of I-INCE 1993, Leuven, Belgium (AC, GV)
- Chair Forum Acusticum 1996, Antwerpen, Belgium (AC) [48]
- Chair Gordon Conference on Photoacoustic and Photothermal Phenomena 2001 (JT, DF) [57]
- Chair 15th International Conference on Photoacoustic and Photothermal Phenomena (ICPPP19) 2009, Leuven, Belgium (CG) [58]
- EAA summer school in Leuven 2019 (MR, AK)

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ACOUSTICS RESEARCH AT TPD-TNO IN THE 20th CENTURY

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ABSTRACT

TNO is a leading Dutch organization for Applied Scientific Research ('Toegepast Natuurwetenschappelijk Onderzoek'), founded by Dutch law in 1932. One of its institutes was TPD ('Technisch Fysische Dienst'), focused on Technical Physics. Applied acoustics research at TPD started in 1941 in close cooperation with the Technical University in Delft. Initially it mainly covered room and building acoustics, extending in the subsequent years to environmental noise, ship acoustics and machinery noise. The research combined experimental work and modelling, often resulting in contributions to guidelines, legal regulations and (international) standards. The source-transmission-receiver chain was a common starting point, resulting for instance in measurement methods for source description, reciprocal methods for the measurement of transmission and sound transmission prediction models. In close cooperation with other TNO institutes appropriate quantities and allowable levels for noise annoyance were defined. The nature and impact of applied acoustics research will be highlighted, showing some examples from the fields of building acoustics, outdoor sound propagation of road, railway and industrial noise, structure-borne sound source characterization and transmission of ship and machinery noise. Finally, a view is given on the links to current and future research in this context.

Keywords: *acoustic research, history, building acoustics, outdoor sound propagation, ship acoustics*

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1. INTRODUCTION

Acoustical activities in the Netherlands started around 1930, initiated by prof. Zwikker at the Technical University in Delft, with a focus on noise abatement, building and room acoustics. In 1934 the 'Geluidstichting' (Sound Foundation) was founded, the predecessor of the Acoustical Society of the Netherlands. The activities of that foundation were wider than scientific research, there was a service for measuring and advising and activities to make the general public aware of noise problems. Research and contact with foreign institutes in Germany and the United Kingdom were mainly maintained through the University. In 1932 TNO was established by the Dutch government, the organization for Applied Scientific Research, dealing with a variety of scientific subjects for the benefit of Dutch society. After some discussion it was thought that the practical work of the 'Geluidstichting' would better be placed under the umbrella of TNO, but maintaining the strong link with the University and for that purpose in 1941 the Institute of Applied Physics was founded with the link to TNO and university indicated in the official name: TPD TNO-TU. The institute was also housed in the physical department of the university, as it would be throughout the 20th century. At the start of the institute acoustics was the prime subject while other areas of research at the university, such as heat transfer and optics would become important items too. Another TNO institute was also involved in noise as a health factor and at the start there was close cooperation concerning subjective effects and annoyance.

2. ACOUSTICS AT TPD

In the first period the research and development were mainly done at the university while the application - measurements, advice - would be done by TPD. Over the years this partly shifted. The focus was on building

acoustics and room acoustics, and therefore the properties of building materials for sound transmission and absorption. Measurement methods needed to be developed, measurement devices created and practical knowledge gained. Plans to develop test buildings for this purpose were hindered by the ongoing war, but could be started soon after the war. Prof. Kosten promoted a lot of the work and TPD assisted in the first ICA congress (1953) with a lot of attention to building acoustics, which was especially needed in the light of the post-war reconstruction efforts in Europe, partly with new construction methods and materials. Later, other acoustic topics also got attention. Increasing traffic caused noise annoyance by aircraft, cars and trains as did growing industrial activity. Furthermore, high sound levels caused health problems at industrial plants and on board ships. In the eighties and nineties, new disciplines were introduced to address future needs: low noise design at the source, active noise control, flow acoustics, acoustic imaging and numerical modelling of sources and sound propagation. Specific models were developed and applied, such as a national method for shooting noise from civil and military training areas, with parts also included in ISO standards [4]. Also models and tools for wheel/rail rolling noise, bridge noise and tyre/road noise were developed. TNO had a key contribution to the development of the PIEK noise programme for reduction of noise from goods delivery, later formalized and adopted in several other countries [5]. As the variety of subjects is rather wide we will further concentrate on three main topics with international impact: Building Acoustics, Ship Acoustics and Outdoor Sound Propagation.

3. ACOUSTICS RESEARCH HIGHLIGHTS

3.1 Building Acoustics

As said, to characterise materials and buildings, acoustics quantities and appropriate measurement methods and devices had to be developed. The main contributions from the Netherlands came through the university - prof. Kosten - with practical help and assistance from the TPD. This led to internationally agreed methods, standardized in ISO. The low number of the standards indicate the early work on this: ISO 140, measurement methods for sound insulation of materials and buildings; ISO 354: measurement methods for sound absorption of materials and ISO 717: requirements for building performance.

The latter requirements were largely linked to the typical performance of good German buildings, so-called 'soll-curves', both for airborne sound and impact sound. Partly while construction methods were not identical in the Netherlands it was questioned whether these were appropriate. So TPD participated in research by the health institute of TNO about the appropriate requirement for airborne and impact sound insulation. This was conducted along the line of source-transmission-receiver, first of all for airborne sound. To characterise the desired maximum transmission it was questioned what is the dominant source (radio music and speech) and what is an acceptable received level (Noise Rating-curve, more or less equivalent to A-weighting, at background sound level). To describe the source people were asked to choose the best listening level of the radio and that level and spectrum were measured. Quite a job at that time, the octave band filters for instance had to be defined and were produced by TPD, using remnants from American military equipment. The results more or less confirmed the curve in ISO 717 [6].

In the sixties a comparable study was done by TPD for impact sound, since social surveys showed that heavy concrete floors were much better judged than according to the ISO 717 curve. The approach was the same: what is the relevant source (walking) and what is an acceptable level (NR-curve). The typical relevant difference on various floors was deduced from the sound level peaks by human walking and by applying the standardized impact machine [7].

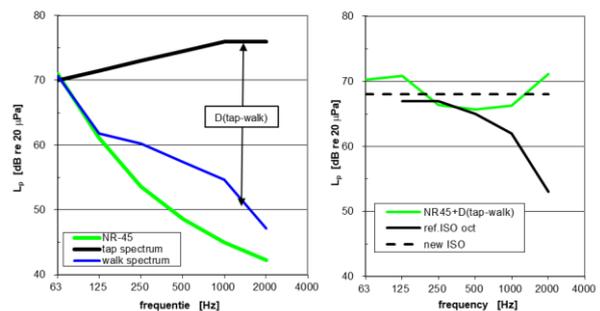


Figure 1: Applying the difference in sound level between tapping machine and walking to a concrete floor, thus comparing walking spectrum peaks with NR curve (left) or applying this difference to the NR curve as a direct reference for the tapping machine (right).

That tapping machine was not developed as a representative impact sound, but to provide a load and constant impact sound to facilitate measurements. The result is illustrated for a heavy floor in Fig. 1. For impact sound there clearly is a large difference between this result and the ISO curve. That resulted in changes in the Dutch requirement and only many years later this system was more or less added as an alternative to the ISO standard.

With the requirements fixed it becomes important to realize buildings that fulfil them and to give guidelines to the designers and builders of housing. So in the seventies a lot of attention was given to better understanding the sound transmission between rooms with various building constructions. And it was felt that a transmission model was needed to derive those simplified guidelines. A basis for such models was more or less available, mainly from German literature, but a lot of details were missing to sufficiently describe the direct and flanking transmission, see Fig. 2.

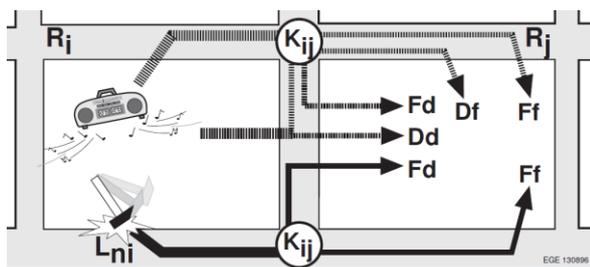


Figure 2: Illustrations of the direct and flanking transmission path between two rooms, indicating the relevant describing quantities.

The vibration transmission over the junctions was important (K_{ij}) and for heavier building materials the in-situ damping, depending on the construction situation, as characterised by the structural reverberation time. Measurement methods were developed to determine those quantities and data gathered in various buildings [8]. The transmission model derived from these results was used to create guidelines for builders.

The increased attention to road, rail and aircraft noise also made it necessary to consider the sound transmission through facades and the increased number of equipment and installations in buildings. Prediction models for these items were also developed. And for the equipment noise good use could be made of the

knowledge gained at TPD for mounting and describing structure-borne sources in ships (see 3.2).

In the 1990s a new EU regulation for products and materials actually required a link between the properties of building material and buildings. So some buildings acoustics transmission models needed to be standardized and these results formed an important input to the new European standards EN 12354, part 1 (airborne sound), 2 (impact sound), part 3 (facade) and part 5 (installations) [9]. Some parts of these standards later became ISO standards, indicating a wider need and use than Europe.

3.2 Ship Acoustics

The propellers and engines of ships are strong sources of sound and vibration and the steel ship structure facilitates transmission to the cabins and into the surrounding water. The latter is of course of prime importance for naval ships, but in general also for underwater life as became clear later. To tackle these problems TPD started around 1950 with a lot of measurements aboard ships to gather data. Combined with the available general knowledge at the university about vibrations, scale model rules and properties of rubber, this allowed fruitful developments of less noisy sources (propeller, gears) and better resilient mountings for engines.

In the 1970s this new knowledge led to prediction models for the sound and vibration transmission in ship structures. It also led to the development of dedicated laboratory setups for detailed research such as a test bench for resilient mountings, and a reverberant water basin that was constructed as an inside-out ship to test and improve different solutions for resilient mounting and constructions (see Fig. 3). Although much of the research was done for the Dutch navy, the spin-off was beneficial for the consultancy work for commercial shipyards, varying from seagoing ships to the Rhine barges. As pioneers in ship acoustics, TPD organised two international symposia on ship acoustics [10].

Two specific research tools were developed and used in this area, namely the application of reciprocity in measurement [11],[12] and scale models to study structure-borne sound transmission and exhaust noise systems and silencers. Reciprocity allows us to measure the velocity of the ship structure due to a sound source elsewhere instead of measuring sound pressure at that point due to forces excited on the structure at several points; see Fig. 4.

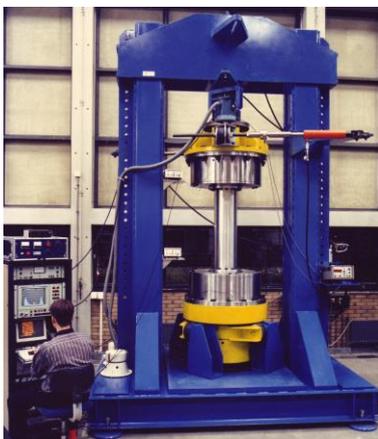
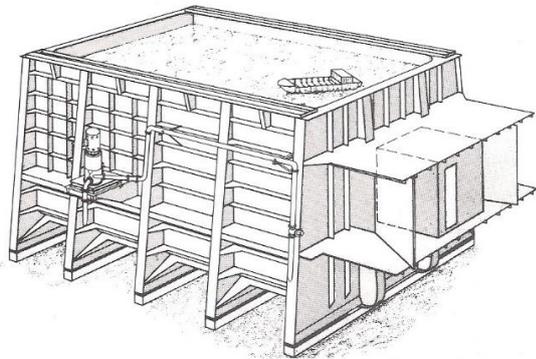


Figure 3: Top: Reverberant water tank as inside-out ship and bottom: test bench for resilient mountings with appropriate preloading.

For structure-borne sound this is especially beneficial since the excitation has 6 degrees of freedom (force and moments in and around x , y , z -axes) compared to the 1 degree in airborne sound transmission. Furthermore, there is the practical advantage, both in airborne and structure-borne sound transmission that microphones and accelerometers are much smaller and easier to mount in a complex source environment than big loudspeakers and exciters.

A specific example of reciprocal experiments is the case where the sound source cannot be decoupled, such as a cavitating propeller. Still then, the source strength can be determined by considering also the sound source in the reciprocal experiment as a microphone in the direct experiment by measuring the open voltage of the loudspeaker.

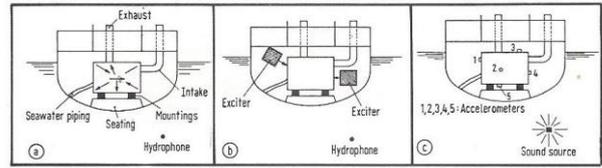


Figure 4: Options to measure sound transmission through a ship's hull into water: (a) measuring path transmission is hardly possible, since decoupling of paths is not possible in working condition, (b) exciting at sources is often practically difficult and what is the appropriate source position, (c) accelerometers are easily mounted in all positions and for all measuring directions.

Another important aspect is the adequate description of structure-borne sound sources. Airborne sound sources can normally be described independent of the surrounding, by sound power and directivity for instance, but for structure-borne sound sources with multi degrees of freedom and coupled to the surrounding structure that's not so evident. Much work has been done to find practical and sufficiently reliable descriptions, varying from equivalent forces to modelling with blocked forces and internal impedances. This work also resulted in a number of international measurement standards which are not only applicable to shipboard equipment but to equipment in general.

Towards the end of the century, the experimental work was more and more supported by development of calculation models [13] that led to a better understanding of the underlying mechanisms and showed to be sufficiently accurate and of course easier to apply. The knowledge partly developed in ship acoustics was also put to use more broadly. Low noise design of machinery and equipment was taken up in the eighties and applied to products varying from MRI scanners to automotive and railway components and bridges. The combination of empirical and modelling techniques, including scale modelling, provided a strong knowledge base, available to TNO's clients.

3.3 Outdoor sound propagation

While the attention after the second world war was on reconstruction and thus on building acoustics, the growing mobility and industrialization led more and more to noise nuisance due to road traffic, air traffic, rail traffic, shipping and industrial activities. So as to reduce

the received levels the sources can be made quieter or the transmission of sound can be reduced. TPD could contribute to this mainly for those sources that were also produced or created in the Netherlands - ships, industrial sites, city buses - but hardly for the others. For cars, mopeds and motocross bikes, noise limits were set following a standardized measurement method (type approval or in-situ checks). But often those measurement procedures were not representative for the normal driving conditions. Various studies have been conducted to improve and change those measurement procedures to make them more appropriate. For example, the noise of a stationary running moped is not at all representative, but accelerating at stand still improves this a lot.

To predict the sound level of roads and railways at distance, those source data for cars and trains are not directly useful and sufficient. We need the sound production of traffic flows including the interaction between the cars and the road surface or the train wheels and the rails. In the 1970s large measurement campaigns were conducted to this end and in the nineties the mentioned interaction between vehicle and track was studied in detail, leading to source models for trains (TWINS [14]) and for cars (TRIAS), including the effect of absorbing road surfaces.

The sound propagation from roads, railways and industrial sites is influenced by many factors, but in the early days the influence of the terrain, obstacles and more importantly weather conditions were only partly known. Some available propagation models were empirical models based on dB(A)-measurements and thereby not applicable to other sources. In the 80ties a law on noise annoyance was in preparation that triggered much research to enable accurate predictions of sound levels at distance from industry, roads and rail tracks. Outdoor sound propagation was one of the main points of study in general, deriving where necessary source specific adaptations later. As for many engineering approaches, dealing with octave bands was, and is, considered to be sufficiently general.

To study the influence of weather conditions long-term measurements were performed at distances from a busy nearby highway, acting reasonably as a constant line source, while monitoring the weather conditions. From these measurements it was concluded, among others, that reproducible measurements are only possible within certain favorable weather conditions and the year-average sound level could be deduced from that by applying some statistical adjustments. So the same approach was chosen for prediction methods: calculate for weather conditions that are favorable for the sound

transmission, like down-wind, and apply adjustments to get for instance the year average level. This has of course consequences for the effects of the terrain -soft or hard ground-, screens and objects. And those effects were studied theoretically, with scale models and outdoor measurement campaigns, thus strengthening each other [15].

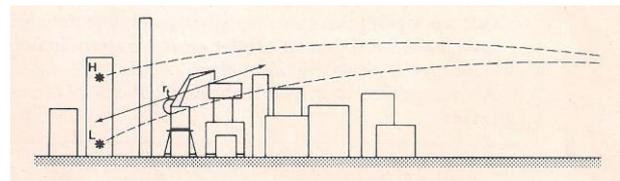


Figure 5: Curved sound ray through industrial installation to determine additional attenuation.

To study the effect of combinations of hard reflecting ground and soft ground, measurements were done in Friesland, a part of the Netherlands with a lot of lakes between grassland. So all kinds of situations could easily be studied there. The resulting propagation model in its most general form was applicable to industry [16] while for road and railway dedicated models were deduced from this. This propagation model was largely adopted also by Scandinavian countries and was a starting point for international standardization at the end of the 20th century [17]. An aspect that had to be incorporated there was the effect of uneven terrain, a neglected aspect in the Netherlands, being as flat as it is.

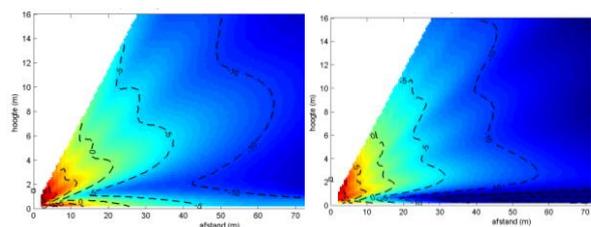


Figure 6: Calculated excess attenuation over hard ground (left) and grassland (right) at 500 Hz under downwind conditions.

4. CURRENT DEVELOPMENTS AND OUTLOOK

Since the turn of the century, acoustics has continued as a key topic at TNO. Today, the main acoustics department at TNO is Acoustics and Sonar, based in The Hague. It is active in the fields of underwater acoustics,

environmental noise and ultrasound technology. Environmental noise has continued relevance due to traffic growth, new infrastructure and more dwellings near roads, railways and airports. Work continues on noise control, propagation and source modelling, experimental methods, standardization and the link with national and EU legislation. TNO was involved in many European research projects including Harmonoise/Imagine, Metarail, STAIRRS, Acoutrain, Roll2Rail, Transit, all relevant for standardization, for example on railway noise source terms [18]. The current EU project LENS is focusing on quieter motorcycles and light vehicles. Also, policy support studies for the European Commission have been performed, including noise source legislation for outdoor machinery [19], and noise policy and impact studies for road vehicles and railways [20]. Underwater sound is a major field of activity, including naval research, sonar technology, and environmental effects of shipping and wind park construction on sea life.

Applied acoustics remains a topic for the future at TNO due to its societal impact, complexity and innovation potential, requiring specific experience and expertise and international cooperation.

5. ACKNOWLEDGMENTS

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40 YEARS INVESTIGATING TYRE/ROAD NOISE AT M+P

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ABSTRACT*

Road traffic is by far the largest source of environmental noise and effective mitigation measures for road traffic noise are essential for improving the wellbeing and health of people exposed to acoustic pollution.

This paper describes the development over 40 years in traffic noise research at M+P Consulting engineers in the Netherlands. It starts with the observation that tyre/road noise is the dominant source of traffic noise, not only from highways but also in urban areas. Very soon it became clear that in the generation mechanism of tyre/road noise the tyre is the source of acoustic emission but that the road surface is the decisive parameter for how much noise is emitted by the tyre. Therefore the development of low noise pavements has become one of the most important tools available to reduce the emission of traffic noise.

The paper follows the growth of knowledge and technology on tyre/road interaction noise at M+P over 40 years and highlights some of the key developments.

Keywords: road traffic, pavement, tyre, tyre/road noise

1. INTRODUCTION

The history of controlling road traffic noise is as old as the road traffic itself. Already in the middle ages horse wagons and coaches were not allowed to enter the city during night-time. In 1865 the UK Red Flag Act stipulated that a person with a red flag shall walk in front of a vehicle with a combustion engine in order to warn bystanders for the terrific noise produced by that vehicle. In the first half of

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the 20th century road traffic was characterized by frequent horn honking, partly because of the regulation that at each crossing one should warn other vehicles and also because pedestrians, cyclists and other road users used the same space without taking care of the ever increasing number of cars. After the misuse of horns was taken care of by changing the regulations, educating other road users to stay at the right (left) side of the road and to cross roads perpendicular and fining misuse of the horn, road traffic noise became equivalent to exhaust noise. Consecutive national and European regulations introduced in the seventies controlled exhaust noise and power train noise in general by formulating maximum levels for road vehicles under full throttle conditions specified in ISO 362 test procedures.

Traffic noise levels however refused to decrease or even stabilize, partly because of growing traffic intensity but mainly because a major contribution was overlooked: tyre/road noise.

In the eighties M+P, among others, in the Netherlands identified that gap and started research on the origin and the nature of the rolling noise emission of road vehicles.

2. ROLE OF TYRE AND PAVEMENT

The starting position for the research program was that tyre and pavement both contributed to the noise production. Nor a freely suspended spinning tyre, nor an isolated pavement produces noise. Only the interaction between the two resulted in sound emission.

The focus was however soon directed to the pavement because that could be studied on a national scale with access to local or national road building technology. Tyre technology lies within a limited group of large manufacturers operating on a European or world-wide scale. Furthermore, noise is a local problem and low noise tyres, however important, cannot be applied on a local scale only.

It could soon be concluded that this was an excellent choice. In the research program it was found that the effect of variations in the pavement was much larger than the effect of variations in the tyre (Figure 1). It shows that the noisiest tyre on the low noise pavement emits several decibels less than the most silent tyre on the noisiest pavement, with the biggest gap at high vehicle speeds.

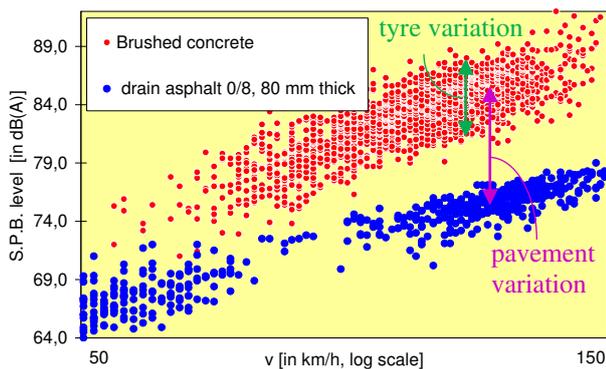


Figure 1. Measured pass-by maximum sound level vs. vehicle speed on transversely brushed concrete and 80 mm 4/8 drain asphalt

The focus on road pavements was further enhanced by the interest in Netherlands in porous pavement types, initially not for noise but to prevent traffic congestion in rainy conditions. The suppression of splash and spray allows road users to drive with high speed and small inter-vehicle distance while preserving safety.

Aligned with that interest M+P started doing noise tests on experimental porous road sections and found that the drive-by sound of vehicles on those sections were several decibels lower than those on conventional dense asphalt concrete, as porous surfaces turned out to effectively absorb tyre/road noise

3. DEVELOPMENT OF THE RESEARCH PROGRAM

3.1 Eindhoven Airport proving ground

In the early '90s, the possibility to use a deserted runway on Eindhoven Airport presented a major boost to the research program. Instead of being dependent on the local traffic stream and vehicle population to do any noise measurements, we could perform specific tests control all relevant parameters, vehicle type, vehicle speed, tyres and pavement type.

A series of nine pavement types were applied in two rows next to each other. There were two dense asphalt concrete sections, one with a moderate and one with fine texture, and seven porous asphalt concrete sections with variations in stone grading, thickness and aggregate type. This included two sections of double layer porous asphalt concrete. Each test section was 3 m wide and 80 m long. It was an ideal playground for acoustic research on tyre/road interaction.

3.1.1 Controlled pass-by testing of cars

The lay-out allowed recording of L_{Amax} and sound exposure levels (SEL) of individual pass-by events of cars with speeds ranging from 40 to 120 km/h. The test fleet of 20 vehicles was matched statistically to the Dutch average vehicle fleet, taking into account the age, engine type and vehicle weight. In that way, a complete assessment of the performance of the pavements with respect to Dutch conditions could be made. Pass-bys were mainly done under *coast-by* conditions: to minimize the influence of engine and exhaust noise, the engine was switched off while driving, resulting in a free rolling vehicle with no powertrain noise. Also, a smaller but still complete set of data under *cruise-by* conditions (constant speed with engine engaged) was recorded to investigate the effect of added powertrain noise.

Additionally a series of tests were performed with a single vehicle equipped with several tyres, including rib and slick tread profiles, to better understand the role of tyre choice on pavement performance.

3.1.2 Findings for passenger cars

The tests showed the large noise reducing potential of two layer porous asphalt with reductions up to 4 to 6 dB relative to a dense asphalt concrete over a wide speed range from 50 to 120 km/h.

It demonstrated the relative importance of the acoustic absorption of the porous pavement and the surface texture. Porous pavements in general exhibit a more coarse texture than dense pavements. Acoustic absorption, when well tuned, more than compensates for the extra noise resulting from this texture.

The systematic variation of tyres and pavement types emphasized the interdependence between tyre performance and pavement type. Low noise tyres (such as the slick type) complete lose their acoustic benefits when rolling on course textures, while smooth textures *enhance* differences between tyres.

3.1.3 Extension with truck tyres testing

Testing truck tyres created new challenges. A single axle, two-wheel trailer was constructed with a wheel load of around three tons. Background noise from the towing vehicle was suppressed by a 10 m bar and an ultra-low noise pick-up truck equipped with extra mufflers, skirts and rib tyres (see Figure 2). This resulted in a reduced vehicle noise that was 10 dB below the L_{Amax} of the passing tyres.



Figure 2. Ultra-low noise towing truck with test trailer used for truck tyre measurements.

A series of different truck tyres were tested, including a slick type, several tyres with a rib or block pattern and an even more coarse off-road profile. Surprisingly the noise reducing capabilities of the two-layer porous pavement for truck tyres were almost equal to that for car tyres.

3.2 Sperenberg proving ground (D)

An opportunity to complete the data set with various dense pavements was presented by the German BAST that awarded Müller-BBM and M+P a project to study the influence of texture on rolling noise in the late '90s. Again, a deserted air field, this time in Sperenberg in former East Germany, a series of 40 concrete and asphalt surfaces were laid with widely varying texture characteristics, ranging from coarse surface dressings to artificial surfaces smoothed by epoxy resins. In addition some sets of experimental surfaces were added with fixed surface textures but varying acoustic absorption and varying mechanical impedances, by including rubber. Rolling noise levels at driving speeds between 40 and 120 km/h were measured for a series of twelve normal car tyres in two sizes and a rib and slick tyre of that same sizes.

The resulting data set proved to be extremely relevant to understand the texture influence on rolling noise, and how tyre tread geometry and texture geometry interact in a specific way.

In an additional project with 16 truck tyres it was discovered that rib types show a sensitivity to texture changes very similar to passenger car tyres, and that block

tyres show almost no sensitivity to texture variations. It further supported the earlier findings at Eindhoven Airport that acoustic absorption is extremely effective in reducing rolling noise for both steer and traction tyres.

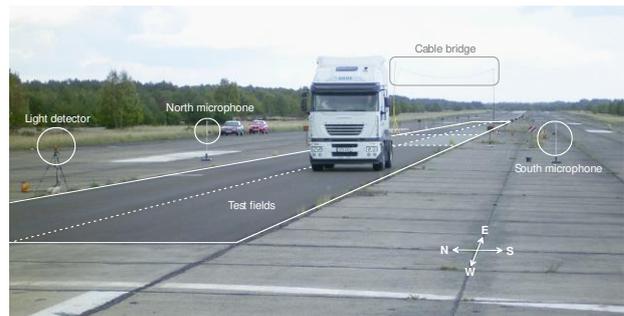


Figure 3. Overview of the Sperenberg proving ground with configuration of two rows of four microphones on each side and light switches between the test sections.

The Sperenberg investigations and the measurement database then formed the basis for the development of the SPERoN simulation model, see below.

3.3 Kloosterzande proving ground (NL)

In 2005 the findings for texture and acoustic absorption were integrated in a research project, commissioned by the Dutch Transport Ministry. The objective was to develop a tool that predicts acoustic performance of pavements taking into account the sound absorption, surface texture and airflow resistance, by hybrid physical/statistical modelling of the tyre/road contact mechanics and the acoustic radiation and propagation of tyre noise over absorbing surfaces, including reduction of the “horn-effect” [4]. The Sperenberg data set was completed with coast-by measurements on a series of 41 pavement types laid at a deserted road in Kloosterzande (NL) that included several combinations of texture and acoustic absorption characteristics. Pavement variations included variations of double-layer porous asphalt surfaces, further discussed in section 5 below. As advised by M+P, there was also room to include some very smooth and very rough surfaces (see Figure 4), outside of the texture range that would typically be applied on normal roads, but very welcome for the tyre/road interaction model development. Also, several rubber surfaces and asphalt/rubber mixtures were tested.



Figure 4. Examples of Kloosterzande asphalt variations: top: two-layer porous asphalt (2/4 mm top layer), bottom: course surface dressing (11/16 mm)

3.4 Twente proving ground

The fourth test area was located in the former military base in Twente. The Scandinavian transport ministries awarded M+P a study into the tyre noise levels of truck tyres on both the standard smooth ISO 10844 pavements and rougher pavements. From earlier studies it was known that for car tyres varying pavements do not only result in differences in average rolling noise levels but also that ranking was affected. The test results for truck tyres showed a similar behaviour, see Figure 5 and more details in [2].

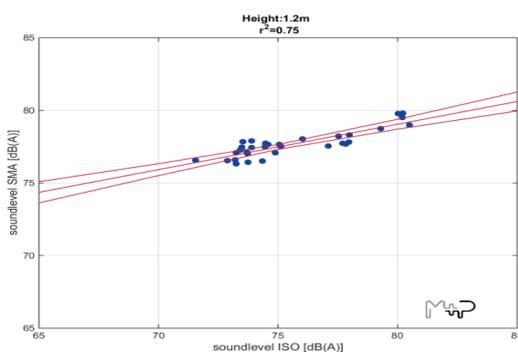


Figure 5. Relation between sound level on ISO 10844 surface and SMA11 surface for truck tyres. Apart from various small changes in ranking, typical is that level differences on a rough texture are significantly smaller than on the smooth texture shown here by the small slope of 0,25.

The study additionally identified a serious noise issue with traction tyres, which are typically used on the drive axle of international cargo trucks. It was found that on smooth textured surfaces, known to cause less rolling noise, traction tyres emit strong tonal noise at the pitch frequency corresponding to the block impacts, and higher harmonics, see Figure 6.

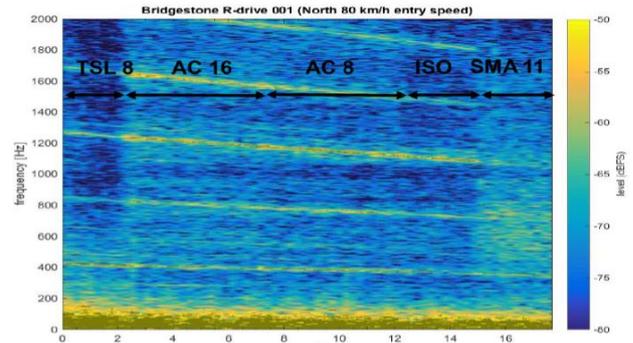


Figure 6. Narrow band spectra of rolling traction tyre over different textures. On smooth textures (e.g. AC8, ISO) the tyres pitch frequency and its higher harmonics are enhanced causing a typical whining sound.

3.5 On board data collection

To investigate the relevance of tyre/road noise in the total road traffic noise under real driving conditions, M+P in the early '00s performed a series of on-board noise measurements, in a research project for the Dutch Ministry of Environment. Several road vehicles, including different types of passenger cars, vans and small lorries, were equipped with data loggers that record vehicle speed, engine speed, accelerator position and sound levels at different positions. Microphones were placed in the engine bay, near the tyre and near the exhaust.

The vehicles were driving on a about 20 km circuit in an urban environment during which the data were acquired with a resolution of 1/s. After normalizing all sound data to an immission level at 7,5 m distance the results were analysed and trends could be identified, see Figure 7. Power train noise turned out to be mainly engine speed driven, while exhaust noise had a clear relation with engine load (i.e. accelerator position). The major conclusion was the dominance of rolling noise also in the urban environment. In our test runs it was found that about 95% of the total emitted sound energy of the vehicle in the urban circuit was tyre/road noise. Already at speeds of 20 km/h rolling noise dominated over powertrain noise, for passenger cars.

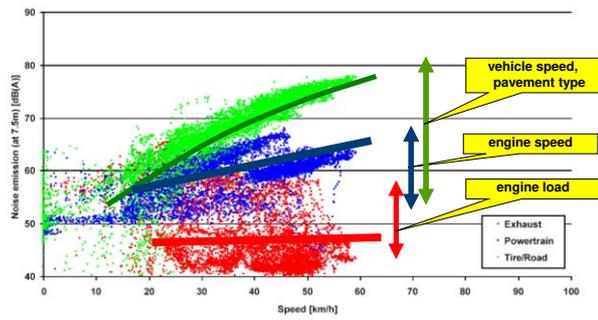


Figure 7. On-board data of a passenger car in urban driving. Each dot is a 1 s sound measurement, plotted vs. vehicle speed. Red: near the exhaust, blue: in the engine bay and green: close to the tyre. Levels normalized to 7,5 m distance.

This study corroborated the importance of understanding rolling noise, not only for traffic noise from medium and high speed roads but also in urban areas where the impact of traffic noise on the population is high.

4. FOUR PILLAR APPROACH

The studies described in chapter 3 constitutes the research work M+P has been involved in. This is only one of the four pillars on which M+P based its approach to traffic noise. The other three pillars we have contributed, and still do, are:

- *standardization* of measurement and assessment procedures and calculation schemes,
- contributions to vehicle and tyre *regulations*, mainly within UN-ECE and EU context,
- *consulting* engineering work for road authorities and road builders.

Experience convinced us that only by an open exchange of data and findings between these four areas, the best overall results can be achieved. It has been our role as a company to facilitate and foster this exchange, bringing government authorities, university researchers, policy makers and standardization committees together. This concept is sketched in Figure 8 and further detailed below.

4.1 Standardization and calculating schemes

The vast amount of test results obtained under controlled conditions on proving grounds was found to be an excellent source to develop and improve procedures described in ISO and CEN standards.

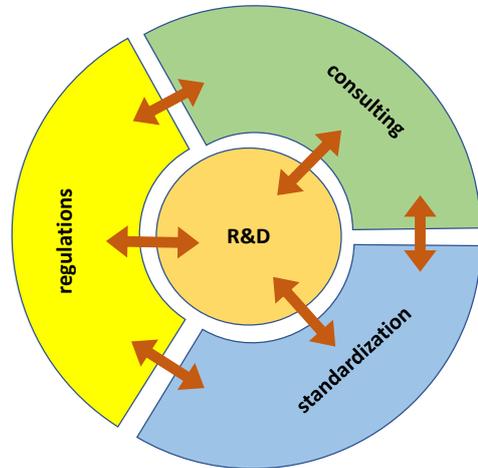


Figure 8. Concept of the M+P approach to rolling noise research. Only by a continuous exchange of data and insights between disciplines effective advancement is possible.

Contributions were made to several noise standards for pavements, vehicles and tyres, such as ISO 10844 on the properties of test tracks for road vehicles and tyres, ISO 11819-1 (SPB) and -2 (CPX) measurement methods for the assessment of the influence of the pavement on traffic noise, the ISO 362 series for the noise emission of road vehicles and ISO 13325 for tyres. In parallel the experiences and measurement data for surface characterisation of the pavement test fields was input to the development of surface texture and in-situ sound absorption measurement devices and related standards such as ISO 13472 for absorption and ISO 13473 for texture.

In the Netherlands, the development and application of low noise pavements saw a big rise in the early '00s. As a result of government grants made available for municipalities to apply such pavements in urban areas, road contractors started to develop a wide range of pavement products. Developments for high-speed roads were further enhanced by a noise innovation programme led by the national road authority, Rijkswaterstaat. Based on CPX- and SPB-measurements performed by M+P and others, the national road noise assessment method was supplied with correction factors to incorporate the effect on calculated traffic noise emissions. These correction factors have later been integrated into the European road vehicle emission model in CNOSSOS-EU (EU Directives 2015/996 and 2021/1226).

4.2 SPERoN model development

Using the initial measurement data from the Sperenberg project, ground-breaking research work was done by Chalmers University (Göteborg), aided by Müller-BBM and M+P, to develop a simulation model that could predict rolling noise levels for different car and truck tyres on any pavement. The pavement is characterized here by its surface texture, airflow resistance and sound absorption characteristics. Tyres are represented mainly by their tyre mobility and 3D tread profile. The model was labelled SPERoN (Statistical Physical Explanation of Rolling Noise), which indicates that it is a hybrid model: the interaction between tyre and pavement are physically modelled to calculate the dynamic contact forces, which are then fed into a statistical model to obtain the vibrational and aerodynamic rolling noise levels.



Figure 9. SPERoN logo

The SPERoN model was later extended with research work from the EU projects ITARI and SILENCE, the German LeiStra projects and the Dutch noise innovation program (IPG). M+P contributed with dedicated measurements of the horn effect, and modelling the effect of pavement sound absorption on the tyre horn radiation efficiency [4], see Figure 10. M+P and Müller-BBM also developed a software application that packaged the SPERoN model in a relatively fast and user-friendly acoustic optimization tool.

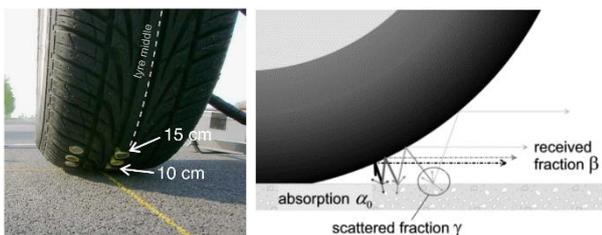


Figure 10. Left: mockup receiver with microphones mounted in the tyre tread; right: modelling approach for sound reflections inside the tyre/road “horn”

Having such a calculation model available is essential for road contractors wanting to develop new low-noise pavement products. With SPERoN, texture, sound absorption and flow resistance could be optimized prior to actual road construction. Using measurements on laboratory test samples, the acoustic performance of asphalt and concrete variations could be assessed and improved, without the need to construct outdoor test sections that allowed actual noise measurements on a passing vehicle.

4.3 Regulatory work

New road vehicles and their tyres have to comply with technical regulations including standards for the noise emission (70/157 EU and amendments or the related UN/ECE regulations R117, R41 and R51). An essential component in this is the test method, which shall be reproducible, representative and universally applicable. Since the pass-by test geometry is very similar to the coast-and cruise-by procedures used in pavement research, we could contribute with insights in L_{Amax} versus SEL data, constraints in the procedures and influence of the pavement and propagation area on the pass-by levels.

Moreover, extensive data from on board monitoring of road vehicle noise and noise data from widely varying tyre populations contributed to the reproducibility and representativity aspects in the method. We were given the opportunity to contribute with these findings in the EU ERGA-NOISE and UN/ECE GRB meetings.

4.4 Consulting engineering

The last but not least pillar constitutes of the numerous small, medium and large projects on acoustic evaluation and monitoring of pavements with the SPB or CPX method. These projects not only generated huge amounts of data, extremely relevant for understanding the initial and age related performance of pavements, but also valuable insights in potential improvements of standardized procedures. The knowledge on tyre/road interaction processes is further increased since not only performance data but also functional data were recorded such as texture and acoustic absorption.

Over the years more than 100.000 individual pass-by events are recorded and CPX data from over 2000 pavement sections could be added to the data base. The data on aging of the acoustic performance of various types of pavements were studied for the European Road directorates (CEDR) and its results made available through <http://www.questim.org/>

5. SPECIAL TOPICS

In this part a few topics are highlighted since their relevance for the field of road traffic noise control is more than average.

5.1 Development of two layer porous asphalt

A special topic in the 40 years of research of M+P is the development of two-layer porous asphalt (Figure 11). Here, a fine-graded open top layer reduces tyre vibration and air pumping noise while a coarse sublayer allows tuning of the acoustic absorption characteristics and increases drainage. First results from the Welschap proving ground in 1989 already indicated a high noise reduction of 5 to 6 dB for cars relative to dense asphalt concrete at medium speeds. Later, a full size test program on several stretches of Dutch highways revealed its potential for durable noise suppression for cars and, importantly, also for heavy vehicles.



Figure 11. Side view of two-layer porous asphalt.

At this moment about 500 km of Dutch highway is covered to maintain noise limits around the infrastructure.

5.2 Development of pavement measurement systems

In order to obtain a full grip on tyre/road interaction noise, experimental data is essential. M+P has developed several measurement instruments for detailed assessment of both the functional performance of the pavement with the statistical pass-by procedure or the close proximity procedure and the intrinsic surface properties such as 3D surface texture and in-situ acoustic absorption.

The technology was standardized in a continuous cooperation with relevant ISO working groups and currently dozens of customers all over the world now use M+P equipment for their specialized pavement research.



Figure 12. Three of the CPX systems developed and manufactured by M+P.

5.3 Development of the harmonized EU noise model

In a close international cooperation within the framework of the EU 4th and 5th framework projects HARMONOISE and IMAGINE, M+P has developed the source model for road vehicles for the EU-CNOSSOS noise calculation scheme. Interesting is that the model distinguishes between powertrain noise and rolling noise. On base of the large data base with on-board acoustic measurements from all kinds of vehicles under a wide variety of driving conditions we were able to develop a coherent description that takes into account age, weight, engine type effects and the relevant influence of the pavement on both rolling noise and powertrain noise. An example for a single vehicle is given in Figure 70 above.

5.4 International cooperation

Since the issue of traffic noise in different countries of the EU shows large similarities, it is efficient to seek cooperation with research institutes in other countries and M+P has worked with several institutes in more than 12 countries in the EU and beyond in the USA and Japan. Such cooperation is stimulated by the European commission by the consecutive R&D framework programs. M+P participated and was WP leader in HARMONOISE, IMAGINE, SYLVIA, ROTRANOMO, SILENCE and recently NEMO. Such programs presented great opportunities to further develop measurement techniques, know-how on tyre/road interaction, road vehicle noise models and create a network that forms the basis of further fruitful bilateral cooperation.

6. DISCUSSION AND CONCLUSION

This paper presents a development of research and development in rolling noise from road vehicles and their tyres over a period of about 40 years. The insight that the pavement is the dominating factor in the generation of road traffic noise has focused the work on low-noise pavements. However, it is impossible to optimize the pavement if the properties of the tyre are not well understood, as the tyre is the main source of road traffic noise. This was shown for smooth (low texture) surfaces that are generally low-noise, but on which some truck traction tyres become very noisy and emit tonal noise related to the block impact frequency.

The development and application of low-noise pavements is still relevant today and tomorrow, perhaps even more so than before. While electrification of the vehicle fleet will minimize the powertrain noise, the tyre/road noise will remain. In the light of the European Commission's recent ambitions in their Zero Pollution Action Plan to reduce the impact of transport noise by 30% by 2030, and given the fact that road traffic is by far the largest source of this impact, low-noise tyres and pavements should be a top priority.

Although 40 years old, the topic of low-noise pavements should keep up with modern times. Today's world focuses on sustainability, climate, energy and air quality, also for road transport. This means that low-noise pavements should also be recyclable and produced at lower temperatures, for instance. Luckily, some of these environmental goals go hand in hand: low-texture pavements are not only low-noise, but also reduce rolling resistance, leading to lower fuel or battery power consumption. Safety, particularly wet braking, does require some micro and mega texture. By careful adjusting texture levels in the different wavelengths areas an optimal balance can be achieved. Low texture also leads to lower tyre wear and the air voids in the pavement do not only absorb sound, but also trap these tyre/road wear particles, preventing them to end up in the soil and waterways. Research on this is increasing, such as in the NEMO project (<https://nemo-cities.eu>), reported also in Forum Acusticum 2023.

As discussed in this paper, the approach to the reduction of road traffic noise, and tyre/road noise in particular, requires work in all of the four pillars presented. For a successful implementation of the research work, it should be closely linked to consultancy, regulations and standardization. Private companies such as M+P have a unique position as they are able to bridge the gap between policy makers, researchers and industry. Policy makers approach us as engineers, supplying data and other

technical information, while pavement and tyre manufacturers ask our help to understanding and implement policy regulations.

7. ACKNOWLEDGEMENT

The achievements of M+P on tyre/road noise, vehicle noise, test procedures and measurement systems has demonstrated the potential of international cooperation. The growth from the first attempts to get a grip on the effect of the pavement in 1986 to the present situation where we are active worldwide as supplier of measurement systems, test track certifications, ISO standard developments and know-how is only made possible by cooperation with many other organisations in- and outside of Europe, and the financial research grants from the European Commission.

More important have been the Dutch ministries of Environment and Transport that have set high standards for our roads, and who acknowledged the value of sharing in the international research arena, supporting the activities in these areas. Also, the German and Scandinavian Transport ministries presented chances for M+P and their partners to perform extensive R&D projects on texture influences on rolling noise for both car and truck tyres.

As a private company, we depend on the dedication of our clients to this research topic. Without their interest and financial support we could not have performed these large research projects and would not have been able to play such a major role in this field over the last 40 years.

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40 years of research comes with many more publications that cannot be listed here. Please visit <https://mp.nl/en/publicaties> for other references.



POLISH ACOUSTICS IN THE LAST 100 YEARS - INSTITUTIONS AND PEOPLE

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ABSTRACT

The paper presents the history of acoustic research and acoustic applications in Poland in the years 1918 - 2000. Before 1918, the Polish state was not on the map of Europe, and there were no Polish research institutions either. In the years 1918 - 1939 in independent Poland, scientific institutions were established and the industry was growing. The development of the reconstruction of scientific life was interrupted by World War II. Polish science suffered huge material and human losses. After the war, scientific life was rebuilt and the organization of scientific life has developed based on three pillars: universities and polytechnics, where scientific research as well as staff training are conducted, institutes of the Polish Academy of Sciences, where fundamental research is conducted, and institutes related to various branches of the economy, where applied research have been carried out. Acoustics is present in all these pillars.

Keywords: *Polish acoustics, history, institutions, people*

1. INTRODUCTION

The paper presents the history of Polish acoustics from 1918 until now. Before 1918, Poland was not on the map of Europe. The territories inhabited by the Polish population were divided between Russia, Germany and Austria. Opportunities for the development of science

were limited. Polish scientists worked mainly abroad. This paper presents the activities of scientific institutions and people whose main area of activity is acoustics. These are primarily universities, polytechnics and research institutes. The profiles of the leading Polish acousticians are described. The activity of associations operating in the field of acoustics, as well as companies that are active in the field of acoustics, is presented.

2. ACOUSTICS IN POLAND IN THE YEARS 1918-1939 AND DURING WORLD WAR II

Leonid Pimonov's (1908-2000) master thesis entitled "System of transverse recording of film sound using a mirror oscillograph" graduated at Vilnius University in 1930. This work can be considered the first scientific paper in the field of acoustics. Leonid Pimonov was scientifically active in Poland, and later in France and Lithuania.

In 1933, Marek Kwiek graduated from the University of Poznań, where he continued his scientific activity on the vibrations of the strings of musical instruments, he also dealt with the theory of acoustic resonances and noise reduction in urban areas. In 1936 he received his PhD degree at the University of Poznań on the basis of the dissertation "The relationship between the physical properties of sound and its audibility".

The problem of the harmful effects of noise has attracted the attention of authorities in many cities. On the initiative of the Ministry of Communication, the Association of Transport Companies appointed the Main Commission for Combating Noise. In 1934, noise

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measurements were carried out in Warsaw, Kraków and Vilnius.

In 1935-36, laboratories conducting research in the field of electroacoustics and telecommunications were established in Warsaw. At the National Telecommunications Institute, Eng. Tadeusz Korn constructed a talking clock used in telephony. In turn, at the National Tele- and Radiotechnical Company, MSc. Eng. Zbigniew Żyszkowski led the team constructing microphones and headphones for telephony, laryngophones and dynamic loudspeakers.

Eng. Ignacy Malecki, in the department headed by prof. Stefan Bryła at the Architecture Faculty of Warsaw University undertook research in the field of architectural acoustics.

All activities related to the construction of Universities, Polytechnics and other schools of similar status were interrupted in September 1939 by the war. Poland was occupied by Nazi Germany. All higher education institutions were closed. The organization of higher education in the underground was dealt with by the organs of the Polish underground state. Many scientists died or were murdered, and many were displaced or went abroad.

PhD Marek Kwiek, who lived in Poznań before the war, was displaced to the so-called General Government. There he was involved in the conservation of church organs and worked scientifically on organ acoustics. He conducted research in the field of musical acoustics.

At the underground Faculty of Architecture of the Warsaw University of Technology, Eng. Ignacy Malecki defended his doctoral dissertation thesis entitled "Physics of porous materials", written under the supervision of prof. Stefan Bryła, and then in 1943 he obtained his habilitation on the basis of the dissertation entitled "Propagation of sound waves in closed rooms". Engineer Zbigniew Żyszkowski stayed in England during the war, where he worked on the construction of radar devices.

3. ACTIVITY IN ACOUSTICS AFTER 1945

After the end of World War II, Poland found itself in a new situation. The country suffered huge losses, both material and personal. State borders have changed. Poland lost its territories in the east. Such distinguished universities as the

Universities of Vilnius and Lviv, as well as the Lviv University of Technology were located outside Poland. In turn, the western border was moved far to the west. Wrocław (Breslau) Szczecin (Stettin), Gdańsk (Danzig) and Gliwice (Gleitwitz) were within the borders of Poland. Before the 2nd World War these cities were important German academic centers.

They started to rebuild scientific life in these areas. A large part of the academic staff rebuilt universities located before the war in Poland: in Warsaw, Poznań, Łódź, Lublin, etc. After the end of the reconstruction period, higher education and science began to develop intensively. Many new scientific institutions were established: universities and research institutes. Over time, three main directions of development were formed: universities, which conducted both scientific activity and staff training, institutes of the Polish Academy of Sciences conducting basic research activities, and research institutes related to individual sectors of the economy. In the further part of the article, we will deal with the activities of individual organizational divisions in the field of acoustics.

3.1 Universities

The term "University" will be understood as institution conducting both scientific activity and educating highly qualified personnel for various areas of economic, cultural and social life, etc.

There are a few research centers in which there are large organizational units at universities (faculty, institute, department), which had the acoustics in their name and in which acoustics or its branch was the main area of scientific and teaching activities. The oldest of them was created already in 1945. At the University of Poznań, Dr. Marek Kwiek obtained his habilitation that year on the basis of the dissertation "Historic organs of the Kielce-Sandomierz region". In 1946, Marek Kwiek created the Acoustic Lab. Later, the Laboratory was transformed into Department of Acoustics. Marek Kwiek educated the staff who conducted research and educational activities in many other centers of the country. Prof. Marek Kwiek was the initiator of the establishment of the Polish Acoustic Society and the Open Seminars in Acoustics. The developing activity of Marek Kwiek was interrupted by his death in December 1962 as a result of a plane crash.

After the death of prof. Marek Kwiek, the Department and later the Institute was taken over by his student, prof. Halina Ryffert, who headed it until 1981. When the Institute was

established, it consisted of 4 departments: Electroacoustics, Room Acoustics and Psychoacoustics, Environmental Acoustics and Molecular Acoustics. In the 2010s, the Institute was renamed the Department again and it was headed by prof. Roman Gołębiewski. The structure of the Department is the same as before the Institute. The Department of Electroacoustics is headed by prof. Ewa Skrodzka, Department of Room Acoustics and Psychoacoustics - prof. Aleksander Sęk, Department of Environmental Acoustics - prof. Anna Preis and the Department of Molecular Acoustics - prof. Tomasz Hornowski.



Figure 1. Marek Kwiek 1913 – 1962

The second academic center with the acoustics as the subject to research is Warsaw. There are three centers with units directly dealing with acoustics: Warsaw University of Technology, where there is a Department of Electroacoustics at the Faculty of Electronics and Information Technology, a Laboratory of Vibroacoustics at the Institute of Fundamentals of Mechanical Engineering, and the Department of Musical Acoustics at the Faculty of Sound Engineering of the Fryderyk Chopin University of Music.

In 1949, the Faculty of Communications was opened at the Warsaw University of Technology, and the Department of Electroacoustics was established there. It was led by Prof. Ignacy Malecki. The Department conducted research in the field of physical foundations of acoustics and

electroacoustics, sound technology, room acoustics, as well as noise control. In the field of room acoustics, Witold Straszewicz has developed a number of acoustic projects for concert halls. After the transition of Prof. I. Malecki to a responsible position at UNESCO in Paris, Dr. Witold Straszewicz became the head of the Department. After the death of prof. Witold Straszewicz, the management of the Department was taken over in 1998 by prof. Zbigniew Kulka. Currently, the Department is headed by prof. Jan Żera.



Figure 2. Ignacy Malecki 1912 – 2004

Laboratory of Vibroacoustics at the Faculty of Automotive and Construction Machinery Engineering Established in the early 1980s on the initiative of prof. Zbigniew Osiński. The immediate organizers of the laboratory were PhDs (now professors) Zbigniew Dąbrowski and Stanisław Radkowski. In its activities, the Laboratory worked on reducing the noise and vibrations of hydraulic excavators and the use of vibroacoustic techniques to diagnose damage to vehicles and machines. The head of the Laboratory is prof. Zbigniew Dąbrowski. The problem of noise and vibration propagation is developing by prof. Grzegorz Klekot.

The Department of Musical Acoustics and Multimedia was established on the initiative of prof. Andrzej Rakowski at the Sound Engineering Department of the Fryderyk Chopin University of Music in 1968. The professor headed the Department for many years. Research was conducted on the perception of pitch and timbre. Over the time, the research topics were expanded to include the area of listening assessment methodology, timbre perception and its training methodology, psychoacoustics and room acoustics. The Department of Musical Acoustics and Multimedia also

conducts artistic activities. The department is currently headed by prof. Tomira Rogala, and the Department staff includes professors Andrzej Brzoska and Andrzej Miśkiewicz.

The beginnings of acoustics at the Gdańsk University of Technology date back to the early 1950s. They are related to the activities of Prof. Zenon Jagodziński. He organized the Department of Radionavigation. In 1982 the Department of Hydroacoustics was established, headed by prof. Z. Jagodzinski. After Prof. Z. Jagodzinski retirement, the Department of Hydroacoustics was headed by professor Roman Salamon. In 2003, the Department of Hydroacoustics was transformed into the Department of Marine Electronics Systems. It was still headed by Prof. Roman Salamon, and after his retirement by prof. Jacek Marszał. Currently, this unit is called the Department of Sonar Systems. The Department worked closely with the Department of Hydroacoustics of the Naval Academy in Gdynia, headed by prof. Eugeniusz Kozaczka and later by prof. Grażyna Grelowska,

Another unit was the Department of Audio Engineering. It was led by prof. Gustaw Budzyński. In 1982, the Department launched the first speciality in Poland, "Sound Engineering". In 1991, the Department was headed by prof. Andrzej Czyżewski. In 2003, the department was transformed into the Department of Multimedia Systems, which has that name of the Department to the present day. In 2012, the Audio Acoustics Laboratory was separated from the Department, and headed by prof. Bożena Kostek.

Activity in the field of acoustics is also carried out at the University of Gdańsk. It was initiated by prof. Antoni Śliwiński in 1970. Prof. A. Śliwiński was a student of prof. Marek Kwiek. Prof. A. Śliwiński established the Department of Applied Physics at the University of Gdańsk operating within the Institute of Experimental Physics. The activities of the Department included ultrasound, molecular acoustics, acousto-optics with interaction between acoustic and light waves, the physical basis of noise control and others. After Prof. A. Śliwiński retired, the management of the Department was taken over by prof. Bogumił Linde. Professor Antoni Śliwiński turns 95 in 2023. At present, experimental research in the field of acoustics is carried out at the Department of Acoustics and Nuclear Physics. It covers environmental and room acoustics, medical

applications of acoustics, as well as acoustical phonetics, phoniatrics and audiology.

The acoustic centers in Upper Silesia Region are the Silesian University of Technology in Gliwice and the University of Katowice. The Silesian University of Technology was established in 1945. In 1969, the Faculty of Mathematics and Physics was established, with PhD Aleksander Opilski as its dean. Research in the field of molecular and quantum acoustics was conducted under his supervision. The subject of acousto-optics was dealt with by the professor Tadeusz Pustelny, while research involving surface waves was dealt with by prof. Marian Urbańczyk. Research in the field of molecular acoustics was developed by prof. Eugeniusz Soczkiewicz. The topic of acoustic emission was developed by prof. Franciszek Witos. Since the early 1970s, research in the field of acoustooptics and photoacoustics has been carried out. They were led by professors Zygmunt Kleszczewski and Janusz Berdowski. These studies were also attended by Prof. Jerzy Bodzenta and doctors Roman Bukowski and Barbara Pustelny. The noise control is a separate topic dealt with by doctors M.Rocznik and R.Hnatków. The acoustics team of the Silesian University of Technology organizes annual Winter Schools: Wave and Quantum Acoustics, and Environmental Acoustics and Vibroacoustic Risks.

Research related to acoustics is conducted at the Silesian University of Technology in the Department of Measurements and Control Systems at the Faculty of Automatic Control, Electronics and Computer Science, headed by prof. Marek Pawelczyk. These studies concern various aspects of active vibration and noise reduction, as well as speech and speaker recognition algorithms.

Since 1980, research in the field of molecular acoustics has been started at the Department of Physical Chemistry at the University of Silesia in Katowice. The initiator of this research was prof. Stefan Ernst. Currently, the Department is headed by prof. Marzena Dzida.

In Krakow, the research center in the field of acoustics is the Department of Mechanics and Vibroacoustics of the AGH University of Science and Technology. Its activity is a continuation of the activity of other AGH research units. In 1952, the Department of Technical Mechanics was established. In 1972, on the initiative of Professor Zbigniew Engel, the Environmental Noise Laboratory was established. The head was prof. Zbigniew Engel.

Professor Engel was the creator of the name "Vibroacoustics". In 1993 Department of Mechanics and Vibroacoustics was created. It was still directed by Prof. Zbigniew Engel, and after his retirement - by Professor Wojciech Batko. Professor Engel built there the laboratory facilities: the building, which is the headquarters of the Department, laboratories consisting of an anechoic chamber with a volume of 1000 m³, a set of reverberation chambers with equipment, a machine diagnostics laboratory, laboratories for testing acoustic materials and vibrating structures, and others. For his activity, Professor Z. Engel was honored with the title of Doctor Honoris Causa of AGH. In later years, the Department was headed by Prof. Jerzy Wiciak. and prof. Tadeusz Wszolek. On the basis of the Department's equipment, the Technical Acoustics Laboratory was created and headed by prof. Tadeusz Kamisiński

Acoustics in Wrocław is practiced mainly at the Wrocław University of Technology. The initiator of research in the field of acoustics was Professor Zbigniew Żyszkowski. He organized the Chair of Wired Telecommunication here. In 1953, he published the book "Fundamentals of electroacoustics", in which he gathered all the knowledge of the time about electroacoustic transducers. Prof. Z. Żyszkowski organized a team of young workers who in their research dealt in acoustics. The interests of doctor Janusz Renowski focused on psychoacoustics, professor Wojciech Majewski - on the speech acoustics, PhD. Edmund Talarczyk - on ultrasound technology, and PhD. Janusz Zalewski on noise control. Prof. Zbigniew Żyszkowski dealt with the problems of electroacoustic transducers. In 1968, the University was reorganized, replacing faculties and departments with institutes and research and development units. Acoustics was present at the Institute of Telecommunications and Acoustics. In the Institute were departments: the Department of Acoustics under the direction of prof. J. Renowski and the Department of Acoustic Signals Analysis and Processing headed by prof. W. Majewski. There was also the Environmental Noise and Vibration Laboratory, headed by prof. J. Zalewski. In 2012 the Department of Acoustics and Multimedia was established, headed by prof. Andrzej Dobrucki. He continued the subject of electroacoustic transducers. In 2019, Prof. A. Dobrucki retired, and the chair was taken over by prof. Krzysztof Opiełiński – specialist in the field of ultrasonic technology.

The initiator of research in the field of acoustics in

Rzeszów was prof. Roman Wyrzykowski in 1966 at the Pedagogical University. Scientific interests of prof. R. Wyrzykowski focused on the issues of analytical acoustics and the theory of vibrations. After Prof. R. Wyrzykowski retired, his work was continued by Prof. Witold Rdzanek. Now, Prof. Wojciech Rdzanek Jr. (son of Witold), together with prof. Krzysztof Szemela, continue research in the field of analytical acoustics at the Department of Biophysical and Structural Research, and prof. Lucyna Leniowska deals with active vibration damping at the Department of Mechatronics and Automation. It can also be stated that at the Rzeszów University of Technology, prof. Adam Brański is active and he specializes in numerical methods of the acoustic field, mainly the method of boundary elements (BEM). Prof. Henryka Czyż, until her retirement also worked at the Rzeszów University of Technology and dealt with molecular acoustics.

In Szczecin, from the 1970s, the Department of Applied Acoustics at the Faculty of Maritime Technology of the West Pomeranian University of Technology is operating. The acoustic research was introduced by prof. Stefan Weyna. The main area of his scientific interests was the modeling, visualization and animation of wave motion in vector diffuse and free acoustic flows. Prof. S. Weyna published several albums with illustrations of acoustic fields under the name "Shapes of sound" (see Figure 3).

At the Faculty of Electrical Engineering of the West Pomeranian University of Technology at the Department of Systems, Signals and Electroacoustics Engineering, research in the field of the electroacoustics has been carried out by prof. Witold Mickiewicz. On his initiative, the Laboratory of Acoustics and Sound Recording Technology was established.

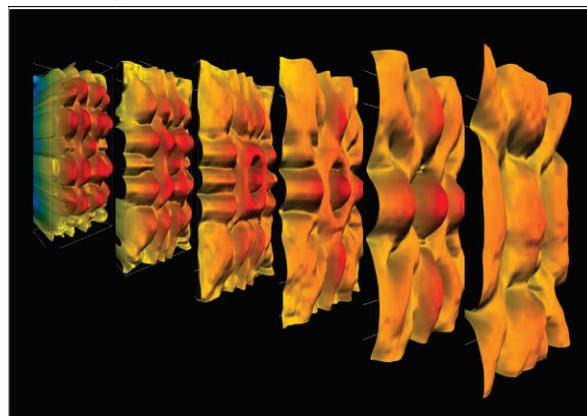


Figure 3. Wavefront in the region of the square waveguide outlet (courtesy of professor Stefan Weyna)

3.2 Polish Academy of Sciences

The Polish Academy of Sciences (PAN) is a state institution whose task is to act for the development and promotion of science and contribute to the development of education and enrichment of national culture. On the one hand, the Academy is a corporation of scientists and creates a network of institutes and units conducting fundamental scientific research.

The network of institutes of the Academy operates within faculties which grouping individual scientific disciplines. The faculties are composed of scientific committees aggregating narrower fields of science. The committees are advisory and opinion bodies related to their areas of activity. The Committee of Acoustics operates within the Department IV of Technical Sciences. It was established in 1964 on the initiative of prof. Ignacy Malecki, who was its first chairman. The Committee is composed of 30 members. On the initiative of the Committee, the quarterly "Archives of Acoustics" was created. The first editor-in-chief was prof. Stefan Czarnecki. "Archives of Acoustics" is an international journal in which researchers from all over the world can publish. Currently, the editor-in-chief of "Archives of Acoustics" is prof. Andrzej Nowicki, who is also the chairman of the Committee of Acoustics. Within the Committee there are thematic sections: Environmental Acoustics, Molecular and Quantum Acoustics, Underwater Acoustics, Ultrasounds and Medical Acoustics and Vibroacoustics.

The proper scientific activity of the Polish Academy of Sciences is carried out at institutes. In the field of acoustics, research is conducted mainly at the Institute of Fundamental Technological Research in Warsaw. The Institute was established in December 1952. One of its founders was Professor Ignacy Malecki, who also became the first Director of the Institute. Initially, the Institute consisted of 4 departments, including the Department of Vibration Research. Later, in 1972 the Department of Analogies (head Dr. Stefan Czarnecki), the Departments of Cybernetic Acoustics (head Prof. Janusz Kacprowski), the Physical Acoustics (head Prof. Jerzy Wehr) and the Ultrasounds (head Prof. Leszek Filipczyński) were created. The Department of Acoustoelectronics was also established under the direction of Prof. Wincenty Pajewski. Currently, scientific activity in the field of acoustics is conducted

mainly by the Department of Ultrasounds, headed by prof. Jerzy Litniewski. The Department also includes professors: Andrzej Nowicki, Barbara Gambin, Tamara Kujawska and Jerzy Wójcik. The Department specializes in medical applications of ultrasound, ultrasonic microscopy and biomechanics. In the Department of Experimental Mechanics research in the field of acoustic emission are conducted by Prof. Zbigniew Ranachowski and his brother Przemysław. At the Department of Intelligent Technologies, research in the field of room acoustics is conducted by Prof. Mirosław Meissner.

3.3 Research institutes

Research institutes are state organizational units established by law to carry out the research tasks related to various areas of economy, culture, health and social life. Research conducted by these institutes are mostly applicable nature and their results are intended to be implemented in practice. In many institutes there are organizational units related to acoustic research.

The Central Mining Institute in Katowice contains the Environmental Engineering Center, including the Department of Acoustics, Electronics and IT Solutions. With the Department of Acoustics for many years prof. Adam Lipowczan was associated and after his retirement prof. Janusz Kompala took over his duties. The Institute conducts research related to the impact of traffic and/or industrial noise; making computer acoustic maps. The impact of mechanical vibrations transmitted through the ground on the structures of buildings and structures as well as on people staying in buildings is tested. Vibro-isolation of machines and devices is designed.

At the Central Institute for Labour Protection in Warsaw the Department of Vibroacoustic Hazards studies the harmful effects of noise and mechanical vibrations in the working environment. The Department was established in 1956 on the initiative of prof. Cz. Puzyna. The next directors were prof. Danuta Augustyńska and dr Grzegorz Makarewicz. Currently, the Department is headed by prof. Dariusz Pleban. The Department has developed stands for testing hearing protectors as well as gloves and materials for protection against vibrations. Hearing protectors with active sound attenuation and an internal communication system have been developed. Noise in classrooms and offices is being studied and means to reduce noise are designed.

Another research institute in which research in acoustics is conducted is the Institute of Environmental Protection in Warsaw. The Department of Environmental Acoustics is in the structure of the Institute. It is headed by Dr. Radosław Kucharski. The Department prepares assumptions and gives opinions on legal acts concerning the protection of the environment against noise, prepares assumptions and supervises the preparation of strategic noise maps, and gives opinions on corrective programs concerning environmental protection.

Research on health risks is carried out by the J. Nofer Institute of Occupational Medicine in Łódź. Within its structures there is the Department of Vibroacoustic Hazards headed by prof. Małgorzata Pawlaczyk-Łuszczyńska. The Department includes also the Noise and Vibration Laboratory.

The Building Research Institute Warsaw exists since 1949. In 1958, the Building Acoustics Laboratory was established. The organizer of the Laboratory and Department was prof. Jerzy Sadowski. He managed the Department until 2004, and after retiring, he handed over the management to Dr. Marek Niemas. Currently, the Department is called the Department of Thermal Physics, Acoustics and Environment. It is headed by dr Agnieszka Winkler-Skalna. It has a well-equipped research laboratory, which includes an anechoic chamber, a set of reverberation chambers for testing acoustic insulation etc. The person responsible for the laboratories is dr Elżbieta Nowicka.

4. COMPANIES

One of the oldest acoustic companies in Poland was Tonsil in Września near Poznań. Tonsil was founded in 1945. It was a Polish manufacturer of electroacoustic transducers, such as loudspeakers and loudspeaker systems, microphones and headphones for home use, and telecommunication cartridges. The company experienced its greatest development in the 1970s. It was one of the largest manufacturers of loudspeakers and telecommunication cartridges in Europe. In the 1970s, Tonsil purchased a license for a complete loudspeaker production line from the Japanese company Pioneer. Tonsil loudspeakers enjoyed an excellent reputation in Poland and abroad. Now, under the name of Tonsil, there is a company that continues the production of electroacoustic transducers, but on a much smaller scale. The president is S. Wieszczeński, and Marek Dutkiewicz, an engineer from

the old experienced staff of Tonsil, is still working for the company. Based on Tonsil's staff, many small companies were established, mainly producing loudspeaker systems. One of them is APS, established in 2006 in Września. It produces professional active studio monitors. Intrada Audio, on the other hand, produces loudspeakers for home use. The president of the company is Michał Gogulski, and PhD Grzegorz Matusiak is the main designer. Another companies producing loudspeakers are Pylon S.A. in Jarocin and STX in Józefów near Warsaw.

The SONOPAN company was established in 1974 as a branch of the TECHPAN Experimental Department of the Institute of Fundamental Technological Research of the Polish Academy of Sciences. In 1992, the company transformed into an independent company SONOPAN Ltd. The company specializes in the production of acoustic measurement equipment. The flagship products are condenser measurement microphones. The company also produces microphone preamplifiers, RMS detectors and acoustic calibrators. An all-weather set for continuous monitoring of noise in cities, sound level meters and a system for measuring acoustic power are also produced. All products are original company designs. The main designer of this equipment was engineer Andrzej Bogucki.

The world-class manufacturer of sound level meters and other noise and vibration measurement equipment is SVANTEK. The company was founded in 1990 by Wiesław Barwicz and Hubert Chmieliński. The designers of the instruments were the acquired engineers Ryszard Królewski, Andrzej Podgórski and Ryszard Leoniak. The company's first product was the portable sound and vibration analyzer SVAN 910. Within 2 years, several hundred pieces of this instrument were sold. In 1995, the portable sound and vibration analyzer SVAN 912 was developed. It was a convenient and lightweight device with excellent parameters. In 2003, a new product of the SVAN 948 company entered the market. Since 2006, the company has been producing a monitoring station that enables radio transmission of measurement data. In 2012, the smallest of the meters, the SVAN 971, is produced. In 2004, the production of the SV104 acoustic dosimeter begins. In 2015, an intrinsically safe version of this dosimeter was implemented - SV104IS. In these dosimeters, for the first time in the world, measuring microphones in MEMS technology were used.

In 2009, KFB Acoustics Ltd. was established in Wrocław. It was founded by Filip and Katarzyna Barański. The company's profile includes the design and implementation of anti-noise and anti-vibration solutions in industry, as well as noise and vibration measurements both in laboratory and field conditions. The company operates both on the Polish and international markets, mainly in Germany. In addition to the main scope of activity, the company undertakes activities in the field of architectural acoustics, environment and acoustic education. The company cooperates with universities, e.g. with the Wrocław University of Science and Technology, it implements educational programs available on the Internet, such as ARAC (architectural acoustics) or ACOUCOU (acoustic course for industry). In 2023, a new company headquarters and a set of acoustic laboratories, including anechoic chambers, reverberation chambers and a dynamometer, were launched in Domasław near Wrocław. Measurement rooms are equipped with modern measurement equipment: multi-channel analyzers, specialized software.

5. SOCIETIES

The oldest and most important scientific society operating in all fields of acoustics is the Polish Acoustical Society. It was established in 1961 at the Acoustics Seminar in Szczecin. The group of founding members consisted of 38 people. The initiator of the establishment of the Society was Professor Marek Kwiek. The 1st Congress of the Society, during which the statute was adopted and the Society was formally founded, took place in 1963 in Poznań, after the death of prof. Kwiek. It was established that the seat of the Society was in Poznań. The first chairman of the Society was prof. Edmund Karaśkiewicz. The 1st Congress took place during the Open Acoustics Seminar (OSA), which has a 10-year longer tradition. Currently, the Polish Acoustical Society consists of 7 local branches. The branches organize OSA successively in September every year. On the occasion of OSA, the Congress of Delegates is held, which adopts the work plan for the next year. During the OSA there is a competition named after Marek Kwiek for the best work presented at OSA by young acousticians. In 2023, the LXIX OSA will be organized by the Wrocław Branch of PTA. Branches also organize their conferences including: Winter Schools organized by the Upper Silesian Branch, the Hydroacoustics Symposium (Gdańsk Branch) and the Acoustic and Biomedical Engineering Conference (Kraków). The Polish Acoustical Society is active on the

international forum: it cooperates with acoustical societies in other countries and with ICA, EAA, WCU etc. Polish acousticians were elected to the authorities of these organizations. Currently, the President of the Polish Acoustical Society is prof. Jerzy Wiciak.

Polish Section of the Audio Engineering Society (PS AES) is a part of the international AES association based in New York. The interests of the Society are to conduct research, education, standardization and exhibition activities in the field of audio engineering. The Polish AES Section was established at the 4th Symposium of Sound Engineering and Tonmeistering in Gdańsk in 1991. The initiator of the Section's establishment was prof. Marianna Sankiewicz. In addition to this Symposium, the Polish Section of AES organizes a conference every 2 years "News in Audio and Video Technology" of a more educational and practical nature. Members of the Polish Section also participate in AES Conventions and thematic conferences. The vice-presidents of the AES were: prof. M. Sankiewicz, prof. Bożena Kostek and Dr. Ewa Łukasik. Currently, the Chairman of the Polish Section of AES is Radosław Smoliński.

The League for Noise Reduction was founded in 1971 in Poznań. The first chairperson was Prof. Halina Ryffert. Among the statutory objectives of the League is to cooperate with state administrative bodies and scientific and research centers in combating environmental and human exposure to noise. This cooperation involves the organizing conferences and training, carrying out noise measurements and expert opinions, consultations, interventions, and conducting educational activities on the subject of the threat of noise. In 1979, the seat of the League was moved to Warsaw. Since 1984, the League has been entered on the list of Experts of the Ministry of Environmental Protection, which entitles it to issue assessments and opinions in the field of protection against noise and vibrations. Currently, the chairman of the Main Board is dr Mikołaj Kirpluk. Annually on April 26, the League celebrates International Noise Awareness Day.

6. CONCLUSIONS

The aim of the article was to introduce the international community of scientific and educational institutions, companies and societies operating in Poland in the field of acoustics.



UKRAINIAN ACOUSTICS AT THE TURN OF THE MILLENNIUM

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ABSTRACT

The first acoustic research in Ukraine began in the middle of the 20th century with the creation of the Department of Acoustics and Sound Engineering at the Kyiv Polytechnic Institute and the Kyiv Research Institute of Hydrodevices. The first works were dedicated to the development of electroacoustic equipment, the study of acoustic features of the premises and the design of hydroacoustic buoys and stations. In the first years of the independent Ukraine, acoustic research was aimed at creating the projects of new state premises of complex shapes (lecture theatres, conference halls, etc.). In 1991, the Department of Acoustics introduced the speciality "Medical acoustic devices and equipment". In recent years, the significant results have been achieved in the development of acoustic design and computing methods and in the construction of early passive ultrasound diagnostic devices as acoustothermometer used for measuring the internal temperature of the human body, and an auditory echoscope, which implemented a new method for diagnosing human hearing. In addition, after 2014 the department created and tested a technique for acoustic music therapy for the rehabilitation of individuals affected by the stressful situations. Much attention has been paid to the issues of acoustic signals processing and separating them from noise.

Keywords: *Medical Acoustics, Acoustic Signal Processing Technology, Architectural Acoustics, Hydroacoustics, Broadband Acoustic Ear Echo Spectrometer, Acoustic Thermometer.*

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1. INTRODUCTION

The first acoustic research in Ukraine began in the middle of the 20th century in 1936 with the opening of the Department of Acoustics and Sound Engineering at the Kyiv Polytechnic Institute. Initially, the work was related to the development of electroacoustic equipment, as well as research into the acoustic characteristics of rooms of complex shape.

The establishment in 1956 of the Kyiv Research Institute of Hydro Devices has given rise to the joint personnel training programmes (as a branch of the department was opened at the Institute of Hydro Devices) and R&D in the field of hydroacoustics.

2. HYDRACOUSTICS

Central to the entire field of hydroacoustics, the development of ship systems, aviation target search and track systems using radio hydroacoustic buoys, helicopter and positional hydroacoustic stations was launched. These developments met the international standards and were exported to 26 countries.

A considerable contribution of the Ukrainian acoustic school to the theory and practice of solving the problems of radiation and reception of sound waves, in cases when the voltage on the radiating elements is matched by the sound pressure at an arbitrary point of the medium surrounding the emitter should be noted. This takes into account the interaction of electric, mechanical and acoustic fields of hydroacoustic systems when converting and emitting the energy of emitters into the environment.

In the 20th century, advanced models of naval weapons were created in Ukraine. In the field of ship hydroacoustics, these were hydroacoustic complexes for small, medium and large ships. Moreover, the detection range of underwater objects was approximately hundreds of kilometers.

Such results were obtained due to the theoretical justification and experimental verification of the implementation of digital sonar systems of signal classification using expert systems technology, as a type of artificial intelligence system.

As part of the aviation search and sighting systems, hydroacoustic complexes were created, which were equipped with hydroacoustic buoys based on vector transducers that met NATO standards.

3. ARCHITECTURAL ACOUSTICS

In the first years of Ukrainian independence, due to the need to develop its own state structures and legislative framework, acoustic research was aimed at creating architectural and construction projects of rooms with complex geometric shapes (lecture theatres, conference rooms, etc.) and state building standards in the field of room acoustics and the surrounding environment.

Starting in 2005, researchers of the Department of Acoustics and Acoustoelectronics (the department changed its name in 1982), together with the Research Institute of Building Structures and other architectural and construction organizations of Ukraine, developed a number of regulatory documents on the measurement and evaluation of sound-insulating and sound-absorbing properties of materials, as well as requirements for construction and sound insulation of engineering structures, methodology for calculating sound levels in the environment and buildings. The documents fully meet the requirements of international and European standards.

In recent years, a lot of attention has been paid to the use of noise protection screens. Comprehensive studies of the effectiveness of noise protection screens were conducted using theoretical methods (method of partial areas), computer modeling methods, and experimental studies in the laboratory and natural conditions. A number of problems that did not attract attention before were identified, in particular, the assessment of the effectiveness of noise protection screens located on bridges and viaducts. Based on the results of the research, the department developed software that allowed significantly improve the accuracy of predicting noise levels and the effectiveness of screens with finite sound insulation.

4. MEDICAL ACOUSTICS

In 1991, the specialty "Medical acoustic devices and instruments" was launched at the Department of Acoustics

and Acoustoelectronics, which opened a new page in the history of the development of acoustics in Ukraine

The department's research focused mostly on creating a methodological basis (calculation formulas), its experimental verification, design and creation of experimental samples of new electro-acoustic devices for medicine, namely an acoustothermometer of the internal temperature of the human body; broadband piezo transducers for ultrasound scanners, broadband piezo emitters for ultrasound therapy devices; ear echoscopes. The relevance of the research areas was supported by the evidence that even though the earlier attempts to create such devices were made by other researchers, they made fundamental mistakes in understanding both the principle of operation and key requirements for the devices, which did not lead to success.

Common to the theory was its construction based on electromechanical analogies, bandwidth optimization based on the method of connected circuits, which made it possible to perform calculations based on simple ratios that are uniform for different types of converters. On its basis, the following projects were calculated and put into practice: a single-channel, single-frequency acoustothermometer of the human body, which allows measuring the internal temperature of organs and biological tissues, in real time with an accuracy of 0.2 °C; a therapeutic emitter with a band of 1-3 MHz; ear echoscope – a new objective diagnostic device for measuring the quantitative parameters of the human middle ear in norm.

The absence of an acoustothermometer as a device for passive diagnostics with the accuracy of determining the depth temperature became an incentive for the department's research and the following results. For instance, the department developed the theory of an acoustothermometer of the human body's internal temperature based on thermal acoustic radiation through the skin with an accuracy of no worse than 0.2 °C in real-time using a piezo plate as a receiver of thermal acoustic radiation of the human body. The previously unknown effect of the spatial filtering of diffuse radiation by matching layers has been discovered. As a result, the intensity of the piezo transducer's electric noise significantly exceeds the intensity of the electric noise of the acoustic signal, and, therefore, the accuracy of the temperature measurement is many times greater than the threshold. It was shown that this effect in the case of the focused acoustothermometer, developed at the department of acoustics, using a plano-concave elliptical lens, allows obtaining an accuracy of 0.2 °C at a greater depth and in real-time.

Based on the obtained ratios, the scheme of the acoustothermometer was chosen – a focused

acoustothermometer, in combination with electronic switching of the piezo receiver and a noise standard, which allowed not only to dispense with single-spectral and single-beam sounding, but also to measure the temperature in real time. The Department of Acoustics was pioneering the development of an acoustothermometer, which was calculated and implemented based on the plate piezo receiver, an elliptical lens and blocks of two serial voltmeters.

In addition, over time ultrasound therapeutic emitters gained popularity in medicine. It should be noted that the radiation mode can be either continuous or pulsed. The operating frequency range from 1 MHz to 3 MHz was initially overlapped using a set of single-frequency emitters, the essential disadvantage of which is the need to move them during the procedure. This is caused by the need to avoid local damage due to the possible formation of standing waves and "hot spots".

For the first time, it was the Department of Acoustics that developed a broadband electro-acoustic system consisting of a plate piezo radiator, with one matching layer, and two electrical correcting links, which had a bandwidth of 1-3 MHz and did not need to be moved. An equivalent circuit of a piezo element in the form of a complex oscillating circuit was also used to obtain calculated ratios for the optimal parameters of broadband piezo emitters.

Another area of research focuses on the human hearing device. It was mainly studied to properly formulate the requirements for electroacoustic equipment and equipment for the restoration of hearing impairment. The disadvantage of the existing methods of objective diagnosis of the hearing was that it was necessary to subtract the impedance of the closed section of the external auditory canal between the ear insert and the eardrum from the value of the acoustic impedance of the middle ear. The new method of ear echoscopy proposed by the researchers did not have this drawback. It allows measuring the sound reflection coefficient for one short pulse, that is, to observe the process in dynamics during one sample, which makes it possible to highlight individual features of the ear's oscillatory system. This task is especially important in the case of operative restoration of hearing by replacing the auditory ossicles and for screening the hearing of newborns directly in maternity hospitals. In addition, the ear echoscope eliminates the need to use a pneumatic system, as is the case in acoustic impedance measurement, which is dangerous for newborns.

According to the existing research, the reflection coefficient, and therefore, the magnitude of the echo signal should be small. It was necessary to create a mathematical model of the ear. Using the method of equivalent circuits, it

was shown that the equivalent circuit of the middle ear was two connected circuits.

Based on the equivalent scheme, the formula for the parameter of the middle ear in norm was obtained theoretically and confirmed experimentally by deciphering tympanograms. From a physical point of view, it is a condition for optimizing the parameters of the auditory system to the maximum bandwidth in the speech range – the equality of the unit, the so-called communication factor. From a medical point of view, it is a normal parameter. This made it possible to carry out objective differential audiometry, that is, to determine the loss of auditory sensitivity not only without the participation of the subject, but also separately in the sound-conducting and sensorineural systems.

Having analysed the experimental data regarding the value of the active component of the acoustic impedance of the middle ear in the norm, the principle of sound reflection from the tympanic membrane was formulated: the minimum value of the energy reflection coefficient of the sound from the tympanic membrane and the maximum value of the energy transmission coefficient are close to 0.5. This completely disproved the existing notion that "when the elements of the middle ear are in normal condition, the eardrum absorbs sound energy well and only a small part of it is reflected into the auditory canal, as a result of which the eardrum effectively transmits mechanical vibrations to the ossicles of the middle ear."

5. ACOUSTIC SIGNAL PROCESSING TECHNOLOGY

For all the years of the existence of the acoustic school in Ukraine, a lot of attention was paid to the problems of processing acoustic signals and separating them from noise. First of all, this referred to language processing. The effectiveness of speech communication systems and automatic speech recognition depended not only on the type of speech (commands, processing), but also on the acoustic environment (noise, reverberation) and the characteristics of communication channels (filters, codecs). Therefore, in recent decades, special attention of Ukrainian researchers has been attracted by speech modelling methods in conditions of increased level of ambient noise and signal distortion inherent in communication lines.

One of these methods is the creation of speech corpus-databases in the form of sound and related text files. The greatest results were achieved by specialists of the Institute of Cybernetics of the National Academy of Sciences of

Ukraine and the Ukrainian Association for Information Processing and Pattern Recognition.

In addition, it should be noted the achievements of the scientists of the Department of Acoustics and Acoustoelectronics include the research into complexes of computer programs for modelling and measuring speech intelligibility, formant-modulation method for evaluating speech intelligibility, measurements accuracy of the distribution function of the speech levels of signals.

One of the recent vivid examples in this direction is the participation of the department's scientists in the staging of live acoustic experiments and technical examination of the materials related to the substantiation of the innocence of the Ukrainian citizen Vitalii Markiv, who was accused of the death of an Italian journalist in June 2017 near the Slavyansk city. In November 2020, the Italian court agreed with the conclusions of the scientific and technical materials provided by the Ukrainian side, acquitted Mr. Markiv and returned him to the Motherland.

6. CONCLUSIONS

In 2020, there has been an important reorganization – two departments were invited to join their effort to reinforce the research. The Department of Acoustic and Multimedia Electronic Systems was created as a result of merging the Department of Acoustics and Acoustic Electronics and the Department of Sound Engineering and Information Registration into one unit. The successful and rich history of acoustics in Ukraine has been continuing in the 21st century!

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ACOUSTIC RESEARCH AND ENGINEERING ACTIVITIES IN HUNGARY IN THE LAST HUNDRED YEARS

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ABSTRACT

Hungarian acoustics dates back to 1893 when the „Telephone newscaster” was started. The first radio emission was transmitted from the Postal Experimental Station in 1924. Before WW2 the priority subject of acoustics was centered also around the radio: a number of dedicated studios were designed and built. This in turn drew the attention to the field of room acoustics. The most significant scientist of the second half of the 20th century was T. Tarnóczy, who was active in many areas. He founded a research group at ELTE University, which became an essential research entity of the Hungarian Academy of Science. A similarly important technical center was created at the Technical University under the leadership of Z. Barát.

Electroacoustics was clearly the core activity of the Hungarian acoustic industry. A number of ministries have also founded R&D institutes. After 1990 most of these industrial and ministerial institutions have significantly shrunk or disappeared. Their leading staff members have often founded small businesses, offering engineering services. Research activities were concentrated to certain universities, initially supported by EU-funded projects. Nowadays they represent centers of gravity for various modern acoustic areas.

Keywords: *speech science, electroacoustics, room acoustics, noise control.*

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1. INTRODUCTION

As probably in other countries too, acoustics in Hungary has always been hallmarked by some standout topics of the field, and these accents have changed from time to time. In this paper we make an attempt to present the most important events, processes and the most prominent actors, should they be scientists or engineers. The task is not easy because quite some acoustic institutions have already been vanished due to the political, societal and/or economic changes. On the other hand, as to the knowledge of this author, there is no summative work written on the history of acoustics in Hungary. Consequently, this paper is a first – and surely very incomplete – attempt to summarize the development, tendencies and cornerstones of the topics. Nevertheless, it can perhaps serve as a starting point to work out a more comprehensive and detailed description of our beloved profession.

2. THE OUTSET: TELEPHONE, TELEPHONE NEWSCASTER AND RADIO

The commencement of acoustics in this country dates undoubtedly back to 1893 when Tivadar Puskás has launched his „Telephone newscaster”. Puskás has worked with Edison for one year and he was his representative in Europe, building the telephone network and the first telephone exchange in Paris. After having returned to Hungary, he has built the telephone network and set up the first telephone exchange in Budapest in 1891. Soon after that, he started the “Telephone newscaster”, the predecessor of the radio in 1993, with which he transmitted political and economic news, reports from the Parliament and Stock exchange as well as theatre and concert broadcasting. The first Hungarian radio emission was transmitted from the Postal Experiment Station in 1924. The first “studio”

was a furniture-remover coach on the courtyard, the first radio transmitter was a 250 watt unit installed at Csepel island, south from Budapest. The postal institution played an important role in the development of acoustic communication, inasmuch as G. Békésy, the later Nobel laureate worked there as a postal engineer between 1924-1948.



Figure 1. The first “radio studio” – a furniture-remover coach – on the courtyard of the Postal Experimental Station in 1924



Figure 2. Listening the Telephone Newscaster

Before WW2, the acoustic activities were centred around the radio: a number of studios were designed and built for various programmes. This in turn drew the attention to the field of room acoustics. A good example of the linking of the two is shown in Figure 3, which depicts the subjective test of the than new radio studio #6, around 1933. At that time only the raw structure was finished, the Radio orchestra has played various pieces and Békésy and Dohnányi (music director of the radio) were listening and evaluating various acoustic coatings along the walls.

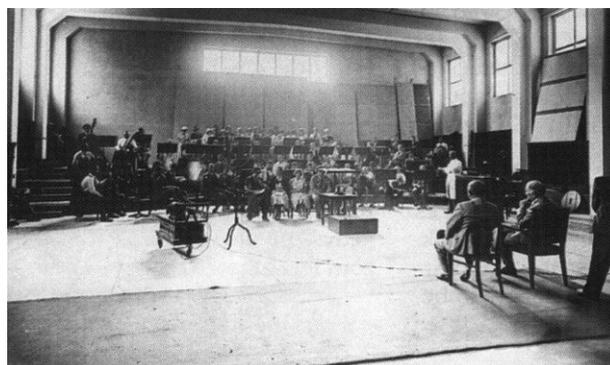


Figure 3. Subjective test to work out optimal acoustic coating of the large orchestra studio of the Hungarian Radio (approx. 1933)

Though rebuilt a couple of times and currently already out of service, the studio still does exist, probably one of the very few – if not the only one – of its sort of other European radios.

3. ACADEMIC INSTITUTIONS AND SCIENTIFIC RESEARCH AFTER WW2

3.1 The Acoustic Research Laboratory and its founder, Prof. T. Tarnóczy

The most significant acoustic scientist of the second half of the 20th century was undoubtedly Prof. T. Tarnóczy, a true acoustic polyhistor. While his favorite research field was speech acoustics, he educated as a many-sided expert in most fields of acoustics from speech and language science to room acoustics, and from bioacoustics to ultrasonics.

He studied the acoustics of speech sounds for his PhD thesis under *Prof. G. Békésy* in the late 1930s. at the Pázmány Péter University Budapest, Department of Experimental Physics. After the war he started the

modern acoustics in Hungary. His aim was to raise the Hungarian acoustics to European level. While teaching at two universities at the same time, he headed first an academic research group, which became later the Acoustic Research Laboratory of the Hungarian Academy of Science. He wrote 11 books, several papers, organized the international contacts for the young professionals in scientific, engineering, and language science, and also in medical and environmental areas of acoustics.

He was one among the early leaders of European acoustics in organising regular international cooperation of acousticians, in order to reach a united Europe instead of a divided one. He participated in the foundation of East-European, later on of the European Federation of Acoustic Societies (FASE), which became the forefather organisation of EAA. The peak performance of his endeavour was the organization of the 7th ICA Congress in Budapest under his presidency in 1971. That event was an epoch-making occasion, bringing together scientists from both side of the late iron curtain for the first time.

research focus of the lab was then speech processing and recognition (see Fig. 6.). Due to the steadily shrinking academic funding the resources were transmitted more and more for the development of measuring instruments and to provide measurement services and expertise. As from 2012 the remnants of the laboratory were split and the parts were attached to two departments of the Budapest University of Technology and Economics, and this is how they operate still today.



Figure 4. Prof. T. Tarnóczy in his laboratory



Figure 5. Prof. A. Illényi in his office at the University

3.2 Further history of the Laboratory

After the death of Prof. Tarnóczy the leadership of the Laboratory went to Prof. A. Illényi (see Fig. 5.) The



Figure 6. Prototype of the speech recognizer with limited vocabulary (1985)

3.3 Acoustic engineering at the Budapest University of Technology and Economics in the 60s to 80s

While Prof. Tarnóczy was active in various fields of the acoustical science, a number of departments at the Budapest University of Technology performed acoustic research and education in some specialized engineering fields. Prof. Szentmártony, who wrote the first Hungarian book on noise control, was an outstanding expert of aeroacoustics at the Faculty of Mechanical Engineering, Prof. P. Nagy has introduced acoustic design into the curriculum of architects and built a testing laboratory for building acoustics. Prof. L. Timár Peregrin acted as valued expert and educator in the field of noise and vibration of electric motors.

Unlike these educational entities which were on the cutting edge but rather small in terms of staff and number of courses, an important and powerful R&D group and educational center was created at the Department of Telecommunication under the leadership of Prof. Z. Barát, He was a true engineer and excellent educator rather than a theoretician, who trained generations of engineers and infected them with acoustics. His major achievement was the development and widespread use of concentrated parameter modelling methods for a wide range of acoustic problems and constructions. His group also gave courses in the field of acoustic engineering, acoustic measurements, sound recording and even noise and vibration control.

4. INDUSTRIAL COMPANIES AND R&D INSTITUTIONS IN VARIOUS FIELDS OF ACOUSTICS

4.1 Electroacoustic industry

After WW1 the Hungarian industry had largely lost its raw material base and fell apart. New industrial sectors had to be brought into being and new product groups generated, attaching special importance to high-level technical development. Radio technology and electrical engineering were leading sectors in this process. Orion Electrical PLC, which was founded in 1924, has produced radio sets and its share from the world market – including the licenced factories – has reached 25 to 30 % by 1942. The fabrication of radio sets was later handed over to Videoton, and Orion came out with electronic instrumentation.

A characteristic example of how politics has influenced the economic activity of industrial companies of that time was the rise of ML (Mechanical Laboratory). The company was founded in 1949 and originally produced

military transceivers. With the easing of cold war tension, the political leadership ordered the company to shift some of the available staff and technology to fabricate sound recorders and other equipment for radio and tv studios. Their products were rather successful and served as the backbone of all Hungarian radios and tvs for decades. (see picture STM210). Nevertheless, when the Hungarian market was open for foreign companies and international competition, ML was privatized and currently operates on a much smaller scale.



Figure 7. STM 210, a successful studio sound recorder of Mechanical Laboratory

The fabrication of electroacoustic products started in the Audio Sound- and Kinotechnical Factory as from 1948. Their product range, at the outset sound amplifiers and loudspeakers, was later extended by PA amplifiers, mixing amplifiers and microphones. All these developments have enabled Audio to step out to the international market, supplying complete PA systems to the stadiums of Moscow and Djakarta. In the 60s multichannel mixing consoles were developed, supplied to many Hungarian and foreign radio houses, opera houses and concert halls.

As from 1960 Audio was renamed to EAG (Electroacoustical Factory), and later to BEAG (Budapest Electroacoustical Factory). The product line was extended by large sound and interpreter systems.

In 1964 BEAG has established its Acoustic Research Laboratory, at the beginning lead by D. Huszty and later by G. Balogh Sr. Their task was to provide applied research for the steadily broadening product lines and to support product development. New products, such as loudspeakers, speaker boxes, horn and cardioid speakers, dynamic microphones and headphones were developed and produced. The number of employees topped 3000, out of which more than 300 engineers, in 1973-74.



Figure 8. FRF measurement of the studio monitor speaker HEC45, fabricated by EAG, in anechoic chamber

The most outstanding successes of BEAG in these years were the following: supply PA and radio transmitting systems of the Moscow Olympic Games as the official supplier of the games; participation in the reconstruction of the Budapest Opera House by its new electroacoustic system; digital PA and speaker system of the Hungarian Parliament and the Comecon Palast in Moscow etc. BEAG has established fruitful cooperation with various departments of the Budapest University of Technology and Institute of Linguistics of the Hungarian Academy of Sciences.



Figure 9. Digital room acoustics modification system, fabricated and installed by BEAG in the Kőlcsey Cultural Centre in Debrecen

At the end of the 80s and in early 90s the market situation has essentially changed, the demand for BEAG products has largely reduced. Most of the employees have lost their jobs, and soon BEAG was discontinued.

However, based on their experience and knowledge, G. Balogh Sr. with his co-workers has established a new company, Interton Ltd. At the time of the foundation they designed and installed PA systems, while their portfolio was continuously broadened later on. Currently they design, install and maintain audio-visual, control engineering and IT systems, commercialise products from the world market and develop and fabricate their own products in five distinct divisions under the name of Interton Group.



Figure 10. Far-field measurement of the IVS sound source (line array of cardioid directivity pattern down to 100 Hz)

4.2 R&D institutions

Apart from the aforementioned academic laboratories, acoustic research and development was mainly deployed to research institutes, belonging to various ministries. The task of Vehicle Development institute, founded in 1950, was to support the newly established automotive factories (Rába, Ikarus, Csepel). Under different names and with often changing organization they set up an environmental protection department later on, dealing

with noise control design, testing and standardisation. The Ministry of Transport established the Research Institute for Road Transport, which built the largest and most developed acoustic laboratory of the 70s, consisting of two reverberation chambers, a good quality anechoic chamber and the first computer aided noise measuring and analysis system of the country. The Ministry of Building Industry ran two institutes: Construction Quality Inspection Institute for standard testing, and Institute of Construction Science for research and development, both having well equipped and staffed. Eventually, the Ministry of Environmental Protection established the Institute for Environmental Protection (see in detail below).

4.3 Activities against noise pollution: standardisation, system of decrees and network of environmental inspectorates

In 1977 the National Environment and Nature Protection Office was created, which was upgraded to ministerial level in 1988. Its supporting institute operated as from 1980. The *spiritus rector* of the field was L. Czabalay, who started his career in the Public Health Institute and joined later the Ministry of Environment and Water Affairs until his death in 1989. It was him who initialized the systematic law-making of noise control, motivated the standardisation in the field and built a nationwide, two-level network of environmental inspectorates. He worked actively in the adoption of international standards to Hungarian conditions and inserting them into a consistent set of prescriptions for standard noise measurement, noise evaluation and noise labelling methods. The system of maximum allowed noise and vibration levels were laid down, controlled and enforced by the inspectorates. Noisy factories were enforced to work out noise control measures, which promoted the field of noise control engineering. R&D institutes, university labs and newly emerging private engineering companies provided services both for design and control.

In spite of the fact that this system has worked more and more efficiently and contributed to the awareness of the risks of excessive noise and vibration as well as to their control as a relevant element of environmental pollution, later developments of the system were by far not so favourable. The Institute for Environmental Protection was merged with the Institute of Water affairs, inspectorates were subordinated to governmental offices and largely lost their professional staff. As a consequence of the growing disinterest of the successive

governments and mainly of the current political leadership, Hungary is one of the very few countries in Europe which has no dedicated ministry for environmental protection. The system of decrees, as set up in the eighties and early nineties is still in force, but both the methods and limit values are obsolete and would need a major revision and updating.

5. ACOUSTIC R&D IN TRANSITION FROM COMMUNISM TO THE MARKET ECONOMY

As shown above, after 1989 it became clear very soon that the Hungarian industry is not sufficiently competitive. With the collapse of the Soviet Union and other, formerly socialist countries, many Hungarian companies have lost their market. Due to the budget balance problems many industrial and ministerial institutions have lost their central funding, and if they were not able to adapt themselves to market conditions, they have significantly shrunk or disappeared earlier or later, or just squirm today. Some of them have atomized and their leading staff members have founded their small private acoustic businesses separately, nowadays offering various engineering services. No doubt at the same time that, fortunately, a few of them were able to gain strength in certain areas and offer wide-range services even on international level (e.g. Vibrocomp International in environmental engineering, Arató Akusztika in room acoustics etc.).

Research activities were driven back to certain university departments, provided that the necessary staff and knowledge was available. This was the case e.g. at the Department of Telecommunication (Budapest University of Technology and Economics, Faculty of Electrical Engineering and Informatics). As from the 2000s a new acoustic laboratory has emerged under the leadership of F. Augusztinovicz, who initiated new activities in the field of noise and vibration control, computer aided acoustic design and numerical simulation. The lab participated in more than 10 EU-funded R&D projects, new equipment and software tools were purchased. Measuring and calculation methods, originally developed for automotive NVH problems were adapted and used for large infrastructural and cultural projects such as the construction of new and renewal of existing metro lines, construction of the vibration isolated Palace of Arts (see Fig. 9 and 10.), renewal of the Liszt Ferenc Music Academy and others. Department of Fluid Mechanics of Faculty of Mechanical Engineering

developed multichannel source identification methods for successful noise control of fans.



Figure 11. Test rig, developed for measurement and optimisation of shock absorber noise. The project was financed by Monroe Belgium and the Flemish government.



Figure 12. Soil vibration measurements at the place of the would-be Palace of Arts by a group of experts (I. Dombi, A. B. Nagy and F. Augusztinovicz)



Figure 13. Elastic support elements between steel brackets (supplied by CDM, Belgium) under the Festival Theatre of the Palace of Arts. Designer P. Forián Szabó (2003-2005)

Another, very positive sequel of the emerge of these new techniques and tools was that 10 to 30 young engineers earn their engineering diploma every year who are familiar with modern acoustics. Their skill has met the endeavour of famous industrial companies to set up development centres in Hungary, dealing with acoustic engineering too. This is the case e.g. of Robert Bosch Hungary who has built a large development Campus recently, Thyssenkrupp Nothelfer in Budapest and Audi in Győr, in close cooperation with the Szécheny István University. These industrial R&D entities perform on-the-cutting-edge work in acoustics and NVH, and their labour demand and formulation of relevant industrial problem for students and young engineers result in ever closer cooperation between industrial practice and academia.

6. SCIENTIFIC SOCIETIES AND OTHER ORGANIZATIONS

In Hungary, acousticians can join various professional organisations. The largest and most traditional society is Scientific Society for Optical, Acoustical, Film and Theatre Technology (OPAKFI), comprising two sections: Acoustical Section and Noise and Vibration Control Section. Both sections organize regular yearly conferences: Acoustic Day and Noise Control Seminar. OPAKFI, as their umbrella organisation has organized a couple of large and renowned scientific events in the past, such as 7th ICA, InterNoise and Active 1997 and Forum Acusticum in 2005. Scientific issues are treated by the Acoustic Standing Committee of the Hungarian Academy of Sciences.



Engineers and other professionals have formed the Acoustic Section in the framework of the Hungarian Chamber of Engineers. This Section is entitled to grant proofs of expert authority – provided that the applicant has appropriate education and sufficient expertise – , which is a must for participating in design teams and expert activities.. Audio engineers have the possibility to join the Hungarian Section of the Audio Engineering Society.

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ACOUSTICS IN THE CZECH LANDS DURING THE 20TH CENTURY

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ABSTRACT

Above all, it must be said that during the 20th century, the Czech lands were part of various state arrangements, which influenced the development of all branches of science and industry. The development of acoustics already dates back to the turn of the nineteenth and twentieth centuries and is particularly associated with the name of Vincenc Strouhal, the author of studies on wires experiencing vortex shedding and singing in the wind. In the period between the wars, the main development of acoustics was connected with the creation of radio and cinematography. At that time, the first companies focused on electroacoustics were founded. The real development of acoustics came after the Second World War, despite being hampered by the existence of the Iron Curtain, when the exchange of information or equipment between West and East was very difficult. In addition to the creation of a number of state-owned enterprises for the development of radio, television, and machine diagnostics, this period is also characterized by active associational activity, which after 1989 came under the Czechoslovak or Czech Acoustic Society. The article summarizes the historical development of acoustics in the twentieth century both in the field of research and in the field of industry and practical applications.

Keywords: *history of acoustics, Czech lands, Czechoslovakia, societies*

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1. INTRODUCTION

First of all, the author must admit that he is not old enough to remember the main moments of the history of Czech acoustics in the twentieth century. He is also not a historian to be able to analyze in depth all aspects of the development of acoustics. Therefore, this text is only his view of what he heard, read or looked up. During the 20th century, the Czech lands were part of various state arrangements from Austria Hungarian Empire through the First Czechoslovak Republic between the wars, the Protectorate of Bohemia and Moravia, the Czechoslovak Socialist Republic to the current Czech Republic and Slovakia. This influenced the development of all branches of science and industry including acoustics. In the text, we will try to look at the field of science and research, at the development of production companies connected with acoustics and finally at professional societies and organizations focused on acoustics.

2. SCIENCE AND RESEARCH

Research into phenomena related to acoustics is associated with a number of famous names in the Czech lands. During the period of the Austro-Hungarian Monarchy, Prague was an important center of science. The famous Charles University was located here, as well as today's Czech Technical University in Prague (which was called the Deutsche Technische Hochschule in Prag in 19th century) founded by Emperor Joseph I in 1707. For example, on May 25, 1842, a lecture "About the colored light of binary stars and some other heavenly bodies" was given by Christian Doppler (1803–1853) at a meeting of the Royal Society of Sciences in Prague. The first experiments confirming the Doppler phenomenon in acoustics were carried out with



locomotive whistles on the then-newly developing railway in the second half of nineteenth century, and due to the impossibility of directly recording and analyzing the changing sound, musicians with absolute hearing were engaged. Other scientists connected with acoustics who found their way to Prague are, for example, the Czech-German physicist Ernst Mach or, for a short time, Hermann von Helmholtz.

The most important Czech scientist was Vincenc (Čeněk) Strouhal (1850-1922), who was a student of the aforementioned Ernst Mach. In 1878 in Würzburg, he defended his habilitation thesis entitled *Eine besondere Art der Tonerregung* (A special kind of toner excitation). In his habilitation thesis, he achieved original results in the physics of fricative tones. He also derived a physical formula for the pitch of the vortex shedding tone (the tones produced by wind flowing over a cylinder or wire), using a constant that was later named after him the Strouhal number and usually denoted St . His most famous period is associated with the construction of the Institute of Physics of the Charles University. At that time he also published a number of textbooks on experimental physics, including a work entitled *Acoustics* (1902). In the years 1903 to 1904 he worked as rector of the university.

After the First World War, acoustics was not systematically taught or studied anywhere. The only exception in the twenties were the lectures of Václav Dolejšek on musical acoustics, who however became famous mainly for his works on the subject of X-ray spectroscopy [1]. At the same time, research work was being carried out at the Czechoslovak Radio, which was focused on the field of spatial acoustics and recording. The first anechoic room was also built in the radio laboratories in Prague [2].

In the period between the wars, there was also the first systematic measurement of noise in the streets of Prague (1935-1937) organized by National Institute of Public Health. It was measured at twenty traffic-frequented places, and on November 19, 1937, the city council declared a day of silence, resulting in decrease of noise of 5-8 phons [3].

From the point of view of the physical approach to acoustics, we cannot fail to mention Professor Josef Bartolomej Slavík (1900-1964). He was born to Czech parents in Bulgaria and moved to the Czechoslovakia only after graduating from high school in the 1920s. In 1927, he obtained the degree of engineer at the Faculty of Mechanical and Electrical Engineering at the Czech Technical University in Prague. In 1928, he became an assistant professor at the Institute of Electrical

Engineering. He later studied physics at the Faculty of Natural Sciences of the Charles University in Prague and in 1936 received the title of Doctor of Natural Sciences. At that time, he was already fully devoted to acoustics, where he focused mainly on room acoustics and the sound system of cinemas and stadiums. After the end of the Second World War, he was involved in the renewal of Czech higher education and founded the Department of Physics of the Faculty of Electrical Engineering of the Czech Technical University in Prague, which he headed until his sudden death during a lecture in May 1964. J. B. Slavík influenced a whole generation of acousticians, including Jiří Tichý (1927-2019), Oldřich Taraba (1922-2007) and Felix Kolmer (1922-2022). The Department of Physics is a leading workplace in the field of acoustics in the Czech Republic to this day. Research in the field of room acoustics, physical acoustics and noise and vibration control was carried out here; the ultrasound group led by prof. Taraba was also significant.

In the field of electroacoustics, we cannot forget Josef Merhaut (1917-2004), who started his studies before the Second World War, but could only finish his studies after it. After his studies, he joined the newly established company Tesla, where he was responsible for the development of electroacoustic transducers. In 1964, he was appointed professor and moved to CTU, where he founded the department of electroacoustics. At the end of the 1960s, he designed and constructed an electrostatic pressure loudspeaker, the solution of which attracted worldwide attention. His assistant and successor was Professor Zdeněk Škvor (1935-2015), who was also an excellent expert in electroacoustic transducers and was the inventor of a number of patents. He contributed significantly to the development of the doctoral study program Acoustics at CTU.

After 1945, state research institutes were also established, some focused on pure science united in the Czechoslovak Academy of Sciences and others focused on applied research. Among them, we cannot fail to mention Research Institute of Sound, Picture and Reproduction (VÚZORT), which was founded in 1945 and represented an important center for the study of acoustics and recording technology throughout the communist period. For many years, the director of the institute was prof. F. Kolmer. Another similar institute was VÚRT (Radio and Television Research Institute) founded at the end of the forties, where they focused not only on electroacoustics, but also on the construction of recording and television studios or the synthesis of musical instruments. After the democratic changes, most

of these institutions were privatized and subsequently transferred to another type of company or disappeared.

3. INDUSTRY

The development of electroacoustics in the former Czechoslovakia was connected (similarly to the development of low-current electrical engineering) with the wider introduction of the telephone and radio broadcasting between the world wars. We can find here, for example, brands such as the Knotka brothers' Microphona (founded 1926) which mainly manufactured telephones, telephone switchboards and later also radio receivers. Especially in the Bohemia, it was possible to find branches of then-starting concerns such as Blaupunkt (originally called Ideal) or Siemens. Everything was interrupted by the Second World War, when part of the manufacturers were absorbed by German companies and transferred to war production. For example, the company Microphona produced aircraft instruments. One of the largest companies was called Elektra Praha and was founded on 18 January 1921 with exclusively Czech capital and sold to the Philips concern in 1932. This company had a wide range of production - light bulbs, tubes and radio equipment, including transmitters and receivers.

After the war, as part of industrial consolidation, all large industrial enterprises were nationalized. In the case of the electrical industry, they were included under the TESLA heading.

The national enterprise TESLA Strašnice was founded on August 10, 1946, through the nationalization and merger of originally separate companies - they were either Czechoslovak companies or, more often, branches of foreign concerns. The naming of the company after the brilliant Slavic engineer Nikola Tesla documents the effort for rapprochement and cooperation between all Slavic peoples. Officially, TESLA was the successor of Elektra Praha, however, it was ceremoniously founded in the headquarters of Microphona.

During the period of socialism and the planned economy, Tesla included all the development and production of low-current electrical engineering. Production plants were located all over Czechoslovakia. It also included some research institutes focused mainly on consumer electronics and telecommunications. For example, Tesla Valašské Meziříčí, founded in 1954, was focused on the development and production of loudspeakers, speaker systems and headphones. From the point of view of electroacoustics, Tesla Litovel

should also be mentioned, where gramophones and later CD players were produced. In Slovakia, let's mention, for example, Tesla Vráble, where amplifiers and sound chains for cinemas and theaters were produced.

After social changes in 1989, individual parts of the company became independent and privatized. Most of these enterprises disappeared over time, because their condition after a long period of communist management made them unable to compete in the new market environment. As an example, let's mention once again Tesla Valašské Meziříčí, which was privatized in 1993 and renamed TVM. In a competitive environment, it survived until 2010, when it disappeared without a replacement.

To mention at least something positive, in 1994 the Italian loudspeaker systems and power amplifier designer Roberto Barletta immigrated to the Czech Republic and two years later he founded the company Xavian Electronic. The company has since grown to become one of the major player in the Hi-Fi world.

4. PROFESSIONAL GROUPS AND SOCIETIES

We do not know much about the association of experts in the field of acoustics in the period between the wars. We only know that there were associations focused on recorded music, i.e. gramophone records. Also in the 1930s, the first Czechoslovak Acoustical Society was founded, but we know nothing about its focus and members (apart from Prof. Slavík) [2]. After the Second World War, there was a rapid development of electronics, which followed on from wartime production. This led to the establishment of various associations. However, after the communist coup, any association that was not controlled by the communist state was suspect. This also applied to acoustics and related fields.

In 1951, the ICA (International Commission for Acoustics) was established, where Czechoslovakia was presented. Following the example of this international organization, in 1959 the Acoustical Commission was established at the Czechoslovak Academy of Sciences to represent Czechoslovakia at the ICA. Logically, Prof. Slavík became the first president and after his death in 1964 he was replaced by Prof. Kolmer. This Acoustical Commission also represents our country in FASE (as a founding member), the predecessor of EAA.

A year later in 1960, the (state-controlled) Czechoslovak Scientific and Technical Society was founded, which consisted of a number of professional associations and

commissions. One of them was the Commission for Environmental Technology, which also included a professional group called Noise and Environmental Acoustics. Among the founders we find names like J. B. Slavík or Jiří Tichý, later the group expanded to include medical doctors focused on hygiene aspects (Prof. J. Havránek) and hearing (Prof. K. Sedláček) as well as electroacoustics (Prof. J. Merhaut). This group included not only educators from universities, but also researchers from industrial research centers. Members of this group, with the support of the Acoustics Commission, organized the first international acoustics conference in 1961, of which a total of 30 were subsequently held. The main undertaking of this group was the organization of acoustic seminars, which have been held twice a year since 1964 (except when large international congresses were held in the Czech Republic and covid pandemy) [4]. The tradition of these was taken over by the Czechoslovak Acoustic Society and, after the division of the republic, the Czech Acoustic Society, and 103 of them have been organized to this day.

The formation of the standard acoustical society was related to the liberalization of the political situation in the country at the end of the eighties. Preparations for the establishment of the Czechoslovak Acoustical Society were already underway in autumn 1989, however, the first meeting was held on April 3, 1990, attended by 119 acousticians from Bohemia, Moravia and Slovakia. The society officially started its activities after the first general assembly, which took place on December 11, 1990 at the Czech Technical University in Prague. Those present elected Dr. Pavel Urban (1930-2021) as the first president, who led the society until the division of the republic. The society, like the republic, was divided into the Czech and Slovak parts on January 1, 1993, and the first president of the Czech Acoustic Society was prof. Zdenek Skvor.

Finally, let us remind you that there are other societies in the Czech Republic that include acoustics. For example, the Czech Society for Nondestructive Testing, which brings together experts in the field of ultrasound and acoustic emissions, is very active. Since the nineties, we have also had the Czech section of the Audio Engineering Society. Understandably, there is considerable overlap between members of individual companies.

5. CONCLUSION

This article is an attempt to summarize the development of acoustics in the Czech lands. It tries to present developments both in the local political context and on a global scale. The author is not a historian and therefore it

was not easy for him to find all the necessary information. It is therefore likely that some important events or persons have been omitted, for which he apologizes.

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ACOUSTIC TEAM AT THE FACULTY OF CIVIL ENGINEERING, STU BRATISLAVA, SLOVAKIA

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ABSTRACT

The main activities of the acoustic team from the Faculty of Civil Engineering, STU Bratislava, Slovakia, are focused on research and education in the room and building acoustics and related areas such as environmental acoustics, archaeoacoustics, noise and health issues etc. During the past years, expertise in psychoacoustics and perception of sound was developed, which resulted in the establishment of a new laboratory that contains a sound-proofed semi-anechoic room suitable also for the performance of the listening test. This paper (1) introduces the acoustic group at SvF STU Bratislava in national and European contexts, (2) describes the evolution of the performed scientific work and education of future architects, civil engineers and material scientists, and (3) shows the interdisciplinary, intersectoral and international dimension of the activities performed here, through collaborations on research projects. Finally, a very tight and essential collaboration with the researchers from KU Leuven (Belgium) and TGM Vienna (Austria) are shown.

Keywords: *acoustics, room acoustics, building acoustics, subjective perception, listening tests*

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1. INTRODUCTION

Research and education on acoustics in Slovakia are present at different institutions. The Room and Building acoustics field is covered mainly by the Faculty of Civil Engineering, STU Bratislava. This Faculty was established in 1939 as a part of the Slovak Technical Highschool (Slovenská vysoká škola technická). In the nineties, the school got a new name: Slovak University of Technology in Bratislava. It has always been one of the most important academic institutions in Slovakia, offering technical education in civil engineering, architecture, water engineering, geodesy, and cartography. The Faculty of Civil Engineering is university faculty, but it prepares both types of student profiles: vocational and university level. (This is because the technical vocational education in Slovakia is present only at secondary school level.)

From historical point of view, after communism fell in 1989, the primary focus of the faculty became the preparation of engineers for the building industry and civil engineering praxis in Slovakia. Due to changes in the political system in the nineties, many large companies have bankrupted or were privatised, sometimes bought by international investors, moving the R&D departments to more developed countries with well-established research & development departments. This situation has caused lack of positions for engineers interested in doing applied research in Slovakia.

Many researchers interested in product/technology development on the industry level have therefore emigrated from Slovakia abroad. In academia the situation after 1990 has changed too. The political changes in the nineties suddenly allowed for the establishment of private businesses. Many professors have taken the occasion of having their own companies while teaching at the



university. This was (is) one of the ways of surviving in the profoundly underfinanced academia in Slovakia.

This situation has however dramatically deformed education by abandoning science and research and focusing very much on daily civil engineering praxis and resulting in a lack of PhD-supervisors that would be genuinely interested in the research (on acoustic).

Consequently, many doctoral students left the country during the past 20 years and went to study in Western Europe or the USA. One of those PhD students was also Monika Rychtáriková, who, in the year 1999 first visited TU Wien (half a year) and later performed longer research stays at KU Leuven, TU Delft and RWTH Aachen. In 2005 she got a researcher position at KU Leuven and also received students from STU Bratislava. Her very first PhD students were Michal Jelínek and Martin Jedovnický [1]. In 2011, Monika became the main supervisor of Vojtech Chmelík (recently assoc. prof. at STU Bratislava), followed by many other young researchers. critical having a dedicated team of experts is crucial. Over the past 10-15 years the acoustic team at STU Bratislava has been formed around Prof. Monika Rychtáriková. The 3 main collaborators (co-authors of this paper) can be considered the main pillars of the acoustic research team at the Faculty, each bringing slightly different expertise (Figure 1).



Figure 1. Acoustic team at the Faculty of Civil Engineering, STU Bratislava, Slovakia

Vojtech Chmelík has finished his PhD thesis “Principles of inclusive design in Architecture and room acoustics” in 2013. He is nowadays dealing with research topics related to room acoustics, acoustic comfort, and speech intelligibility predictions. Daniel Urbán, has finished his PhD thesis in 2015 on Sound propagation within double transparent constructions; and nowadays performs research

in sound transmission, sound insulation. Lukáš Zelem has finished his PhD thesis on the prediction and assessment of acoustic comfort in restaurants (2018). His main research interest lies in psychoacoustics and topics that tackle subjective assessment of sound insulation and standardisation.

2. RESEARCH IN THE FIELD OF ACOUSTICS

The aim of the research of the acoustic team can be seen in three main lines (1) building acoustics, (2) room acoustics and (3) perceptual acoustics/psychoacoustics.

2.1 Building acoustics

In the field of building acoustics, the team deals with various research topics. It is well known that ETICS used for improving of thermal insulation of buildings does not always help to improve the acoustic insulation as well. Researchers prepared theoretical case study, which helps in understanding the relationship between thermal and acoustic performance in building envelopes [2-3].

The team performs both, laboratory measurements as well as theoretical calculations and simulations of building constructions performance also aimed at the low-frequency sound insulation. They also emphasize the evaluation of airborne sound and impact sound insulation, which focuses on assessing the effectiveness of materials and systems in reducing unwanted sound transmission. This research contributes to the development of more efficient sound insulation solutions for various building types and applications as well as measurement techniques for sound insulation evaluation [4-5].

Members of the team have been involved in development of a new method for assessment of sound insulation of walls by means of Laser Doppler Vibrometry. This method offers several advantages over traditional laboratory measurements. Its non-contact nature spatially resolved measurements, and non-invasive characteristics make it a valuable tool for accurately assessing the sound insulation performance of partition walls in various applications [6].

The team also explores the performance of light weight façade constructions, such as double transparent skin facades [7-8].

2.2 Room acoustics

In case of room acoustics, the team addresses several key topics. Large gathering spaces, such as atria and shopping streets, pose unique challenges due to their size and architectural characteristics. Such large public spaces could cover various purposes. The team endeavours to

comprehend the acoustics of these environments, examining aspects such as sound propagation, diffusion, and intelligibility depending on the required function. More often, such spaces are covered with lightweight roofs, including ETFE membranes, which are getting very popular among architects [9-12].

Another topic connected with ETFE membranes, which the group is trying to address, is noise from rain, which is typically radiated into building interior. Depending on a function of given interior space, rain noise can be rather disturbing, especially in terms of communication, since the frequency spectrum of rain noise generated from lightweight roofs in general is often similar to spectrum of human voice. Therefore, it may mask speech, even if the sound level is not too high [13].

Noise in restaurants is another critical aspect investigated by the team. Understanding the sources, characteristics, and propagation of noise in restaurant settings enables the development of strategies to mitigate its impact. By exploring noise reduction techniques and solutions, the team aims to create more pleasant and comfortable dining environments [14-15].

Recognizing the significance of acoustic education, the team focuses on developing methodologies and techniques for teaching and learning acoustics. By promoting an understanding of acoustics among students [16] and professionals, they aim to integrate acoustic principles into architectural and engineering practices more effectively [17].

2.3 Sound perception

A large part of the research in the group involves sound perception and investigation of different phenomena through laboratory listening tests.

Laboratory listening tests help to understand how people perceive sound in different environments and situations [18-21]. Performed studies provided valuable insights into the factors that affect the subjective experience of sound and are essential tool for verification of proposed single number evaluations of sound insulation in building. The topic of single number quantities (SNQ) development in terms of sound insulation quality rating is another aim of the research team [18], [21-22].

The main recent research effort concern speech intelligibility of the Slovak language [23-24] in different architectural settings, such as classrooms etc [25-26], other investigated questions involve different acoustic comfort issues, and during COVID pandemics also the influence of wearing face protection on speech [27]. Additionally, the team has investigated sound source localisation, which

involves accurately determining the position of sound sources in various spaces. The motivation for this research topic is inclusive design of buildings, which serves not only for healthy people and mobility-challenged people but also hearing and sight-impaired individuals [28-30].

3. EDUCATIONAL ACTIVITIES

One of the key activities of the team is the development and delivery of educational programs for architects and civil engineers. These programs focus on the principles of acoustics and the design of buildings regarding the acoustic comfort of users. In particular, two courses on acoustics are offered for future designers of buildings – (1) Building physics 1 – acoustics, which is being taught at the Faculty of Architecture and design. The course is designed to provide students with a comprehensive understanding of the principles and applications of acoustics in the built environment. This course will equip students with the knowledge and skills necessary to create acoustically optimised and aesthetically pleasing architectural spaces. Throughout the course, students delve into the multifaceted world of acoustics and its significance in architectural design. They explore the fundamental concepts of sound, including its propagation, transmission, absorption, and reflection. By understanding these principles, students are able to manipulate sound in various architectural contexts, such as concert halls, theatres, lecture halls, offices, and residential spaces regarding room and building acoustics. The main aim of the course is awareness of the influence of architectural design on sound propagation, including room acoustics, sound isolation, and control of unwanted noise. The second course is being taught at the Faculty of Civil Engineering – (2) Comfort of indoor and outdoor building environment – acoustics.

Within this course, students acquire the knowledge necessary for designing buildings' interior and exterior space in terms of acoustics. Based on the calculation, computer simulation, and measurements, one acquires also theoretical and practical knowledge necessary in the design of schools, office buildings, sports buildings, spaces for musical performances, etc. They are acquainted with the principle of acoustic prediction, the user interface of simulation software, its essential functions and properties and will learn the correct interpretation of results. The aim is to create own virtual acoustic 3D model, calculation of acoustic quantities and so-called “space auralization”. The idea is to use a simulation result as input to the design of building for their master’s theses and design studios.

Students also have the opportunity to collaborate in research in the field of architectural acoustics and the opportunity to present the results at an international conference in the form of a lecture or speech. The educational programs have been well-received by the architecture community and have helped raise awareness of building design's importance towards increased acoustic comfort.

In response to the growing demand from the architects in Slovakia, we have published a book on architectural acoustics [31]. The book explores the principles, theories, and practical implementation of acoustic solutions in architectural acoustics. Through its analysis of sound propagation, absorption, and control, as well as its examination of case studies and design strategies, this book aims to empower architects and designers with the knowledge and tools necessary to create acoustically optimized spaces.

Another part of educational activities of the team is contribution to lifelong learning process for architects and building designers as well as noise awareness. Since past 10 years authors cooperate with companies EUROSTAV, Forum Media, etc. on preparation of lifelong learning conferences aimed at acoustic issues during the building process [32-33].

Among other things, the team has worked to develop teaching materials, case studies, and interactive exercises in the framework of European Erasmus+ Strategic partnerships project "Acoustic Course for Engineers" which is placed on common educational platform ACOUCOU [17]. The platform helps not only architects to better understand the importance of acoustics in building design.

4. COLLABORATION ON NATIONAL AND INTERNATIONAL LEVEL

In addition to their research and educational activities, the team has also been actively pursuing opportunities for funding and collaboration in acoustics. They have applied for several educational and research projects and have collaborated with other institutions and organisations to advance the field of acoustics.

On national level, members of the team are part of the Slovak acoustical association [34], which is also a member of EAA, ICA and I-INCE. Monika Rychtáriková is the president of the association. Vojtech Chmelík represents the Slovak association in the Association of Slovak Scientific and Technological Societies (ZSVTS), a voluntary, non-profit association of public interest, gathering expert

scientific and technological societies, associations, committees and regional coordination centres [35].

The acoustic team (at Faculty of Civil Engineering, STU Bratislava) cooperates intensively also on an international level. There is strong collaboration especially with Laboratory of Acoustics and Faculty of Architecture at KU Leuven in Belgium and the Department of Acoustics and Building Physics at TGM Vienna in Austria. These three institutions have built up an effective consortium and have already participated together in several international projects. The most important project where the acoustic team took part was the H2020-MCSA-RISE project PaPaBuild [36], (2016-2020) which was aimed at (1) improving the diagnostic methods for more precise determination of physical properties of building elements (2) involving subjective assessment of sound insulation to help propose a suitable single number quantity and (3) enabling sustainable product innovation as the result of improved diagnostic methods. The recently on-going project HE-MSCA-DN project ActaReBuild [37] focuses on Acoustic and Thermal Retrofit of Buildings in the EU. It provides research and training by means of new generation of sustainable materials and building components. Doctoral candidates are learning how to improve and guarantee acoustic and thermal performance of buildings undergoing renovation while minimizing embodied carbon production. The project offers 10 doctoral positions.

There were many other projects that the acoustic team took part of. VisegradFund – Noisy Exchange, COST TU0901, COST TD0804, Erasmus+ Strategic partnerships – ACE (Acoustic course for engineers) and others, such as national grants VEGA/KEGA.

To keep connected with the practical world of acoustics, we cooperate with architects, engineers and especially with acoustic consultancy companies in Slovakia and abroad. They often belong to project partners in research projects.

5. INFRASTRUCTURE

In April 2019, the first part of the acoustic laboratory was built that consists of a semi-anechoic, well-insulated room and serves mainly for perceptual experiments (Figure 2). The low background noise is essential for listening tests related to subjective perception of sound insulation. The $L_{A,95}$ in the listening room, is around 16 dB [38].

The laboratory was sponsored by Saint-Gobain company, and it serves all team members including all PhD students dealing with topics related to acoustics – Dominika Húdoková (*Speech intelligibility*), Majid Lavassani

(Assessment of rain noise in rooms covered by structural skins), Michiel Geluykens (*Qualitative assessment of sound insulation of building envelopes and development of an adapted noise annoyance construct applicable for building acoustics issues*).

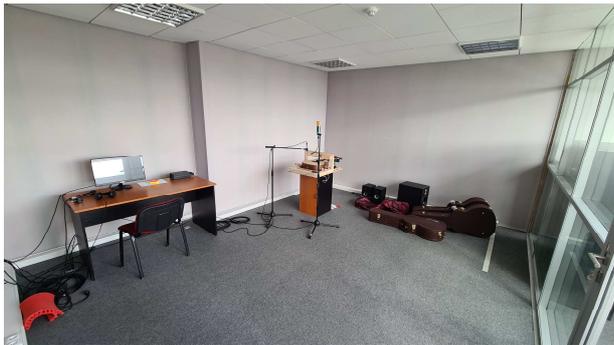


Figure 2. Acoustic laboratory – perception room at The Faculty of Civil Engineering, STU Bratislava, Slovakia

Except for the abovementioned perception room, the laboratory contains classical equipment for in situ measurements (room and building acoustics), set up for measurement of vibrations and several small set-ups such as impedance tube, kit for measurements of dynamic stiffness etc.

6. CONCLUSIONS

In this paper, we have introduced the relatively young acoustic team from the Faculty of Civil Engineering, STU Bratislava, Slovakia, which at the moment consists of 4 senior staff members and 7 PhD students and is well integrated into the Department of Materials sciences and Physics. We intend to explore the present infrastructure and scientific network in the EU, and educate new young researchers, to let them experience the passion for science. Finally, our greatest ambition is to show (by our own example) that also in Slovakia, it is possible to perform a research on acoustics of good quality, in line with research integrity.

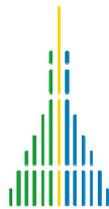
7. ACKNOWLEDGMENTS

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No. 101072598 – “ActaReBuild” as well as Slovak national grant VEGA 1/0205/22.

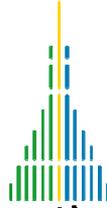
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NOTES ON THE HISTORY OF ACOUSTICS AT ETH ZÜRICH AND EMPA DÜBENDORF (SWITZERLAND)

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ABSTRACT

A brief history of acoustics at the Swiss Federal Institute of Technology (ETH) in Zurich and at the Swiss Federal Laboratories for Materials Science and Technology (Empa) in Dübendorf is presented, focusing on the period between 1920-1970. A first acoustics laboratory was set up by lecturer Franz Max Osswald at the ETH in the 1920s. The work was continued by Prof. Willi Furrer who, together with Prof. Anselm Lauber, wrote a standard work on acoustics. Both authors were associate professors at ETH. However, it was never possible to establish a dedicated chair or institute for acoustics despite the status of the prestigious technical university. Early on, at a meeting in September 1944, the ETH management stated that no separate chair should be established for acoustics because it "eludes scientific research, since it deals mainly with questions of practical application and empiricism". Since then, lectures on acoustics have been held regularly at various faculties of ETH and some research projects have been carried out with remarkable results. However, in 1962 a laboratory for acoustics and noise control was founded at Empa, which is part of the ETH Domain, and is today a recognised laboratory with considerable scientific output.

Keywords: *ETH, Empa, Switzerland, History of Acoustics.*

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1. INTRODUCTION

The main part of the following contribution is based on a PhD thesis completed at ETH Zurich entitled "Hellhörige Häuser. Akustik als Funktion der Architektur, 1920-1970" by Sabine von Fischer [1], a related conference paper [2], the book "Das akustische Argument" based on the PhD thesis [3], as well as the licentiate thesis "Gedämpfter Lärm – die Schweizerische Liga gegen den Lärm 1956-1966" by Mischa Gallati at the University of Zurich [4]. It becomes clear how difficult it is to classify the field of acoustics in disciplinary terms, a fact that is still relevant today and not only in Switzerland. The fundamentals of acoustics seem to have been established long ago, which means that the discipline of acoustics is hardly a subject for physics departments today. But where, if not there, should acoustic sciences be researched and taught at universities?

2. ACOUSTICS AT ETH ZÜRICH AFTER 1920

ETH Zurich was founded in 1855 under the name *Polytechnikum* and received its current name, the *Swiss Federal Institute of Technology (Eidgenössische Technische Hochschule, in short: ETH)*, in 1911. The extent to which acoustics was a subject at ETH before 1920 was not investigated here, but it can be assumed that it was only dealt with theoretically. In 1924, the mechanical engineer Franz Max Osswald (1879-1944) set up a laboratory for applied acoustics and room acoustics (Figure 1). He himself described it as the first laboratory set up specifically for acoustics at a technical university, which seems plausible, especially since the building for acoustics designed by Wallace C. Sabine (1868-1919) at the research institute of the Riverbanks Laboratories in Illinois USA was completed in 1918. With its director Paul E. Sabine (1879-1958), Franz Max Osswald sought exchange with international research

through correspondence [1]. In the comparatively small ETH laboratory and with modest financial and personal resources, Osswald made efforts to follow the international developments in modern acoustics.

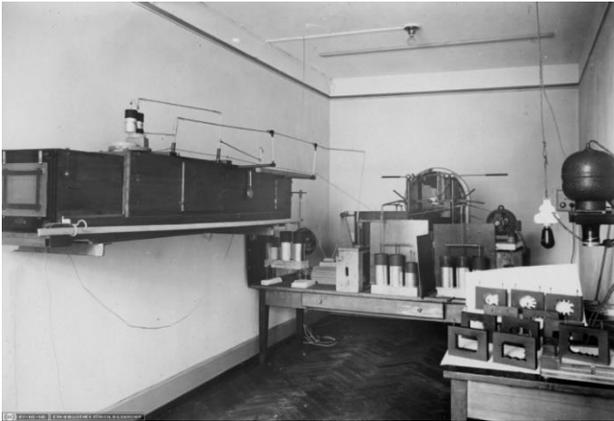


Figure 1 Part of Osswald's laboratory at ETH around 1932 with set-up for sound wave photography with Schlieren technique. Image Archive, ETH Library.

As Switzerland's first university researcher in acoustics, Franz Max Osswald's field of research was linked to a wide variety of disciplines. Osswald later described acoustics as an indispensable complement to architecture, engineering and hygiene. However, as will be shown later, this was not always advantageous for the discipline of acoustics. The two reviews of Osswald's habilitation in 1928 show that the young science of acoustics lacked a disciplinary affiliation: the reviews give the impression that the interest in the scientific research work came mainly from physics, while the architects welcomed the possible applications without being interested in the more precise derivations. In 1929, Osswald was awarded the *venia legendi* of the ETH, neither at the faculty of Physics nor at that of Architecture, but at the Department XII for Electives Courses.

In 1927, Franz Max Osswald's expert report on acoustic designs submitted for the competition for a headquarters of the League of Nations in Geneva, founded after the First World War, the Palais des Nations, was published in detail in Switzerland and later also in the United States. Together with the founding of the Acoustical Society of America (ASA), this episode at the end of the 1920ies marks the moment when room acoustics was recognised as a proper discipline and a crucial function of architecture. Also, the sound wave photographs made by Osswald using a further developed Schlieren technique were of greatest value in communicating the concerns of room acoustics (Figure 2).

However, it seems that the great appeal of the photographs to architects, as well as his own fascination, led Osswald to continue to attach importance to the technique for too long. In the 1930s, however, international experts described it as outdated and inaccurate.

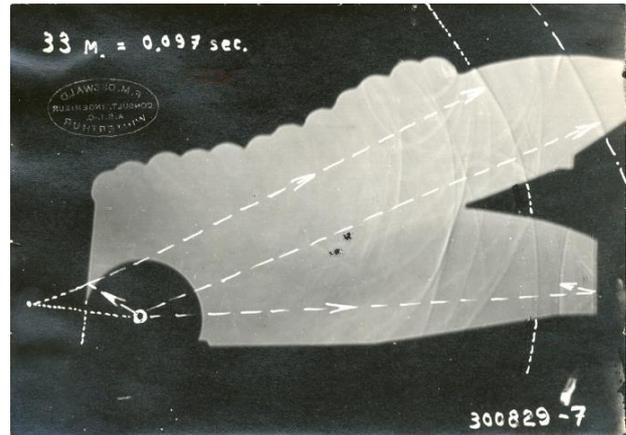


Figure 2 Sound wave photograph in the model of a “concert hall with variable volume” (1930). Image Archive, ETH Library

Osswald also developed his own methodological approaches, such as the “Poch-Variator” (1935), an apparatus for generating airborne and impact sound that could ultimately be judged by the ear (Figure 3), or the “Luftschall-Verzögerungsrohr” (1937), which was intended to serve as a time delay element between different loudspeakers of a sound reinforcement systems of the time (Figure 4) [1].

From 1942, Willi Furrer (1906-1985), an electrical engineer working at the PTT (Swiss Postal Telegraph and Telephone agency), who had habilitated with a thesis on the acoustics of radio studios, taught the subject “Electroacoustics I” at the ETH. After Osswald's death in May 1944, Furrer also took over the teaching of “Room acoustics and sound insulation” at the department of architecture.

The change of generations became an occasion to question the status and scope of the field of acoustics at ETH. In 1944, Alois Muri, General Director of the PTT, approached ETH with the request of establishing a professorship in the field of acoustics. Muri's application was rejected among others on the grounds that room acoustics “eludes scientific research, because it deals mainly with questions of practical application and empiricism”¹ [5].

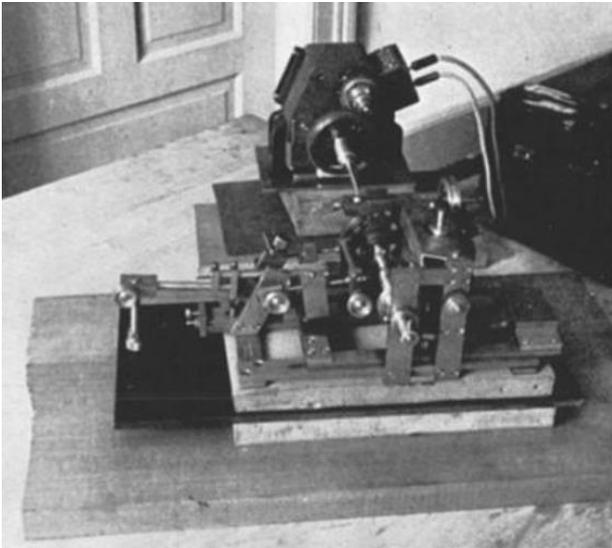


Figure 3 Poch-Variator by F. M. Osswald, 1935. Image: J. Acoust. Soc. Am. 7, 261 (1936).

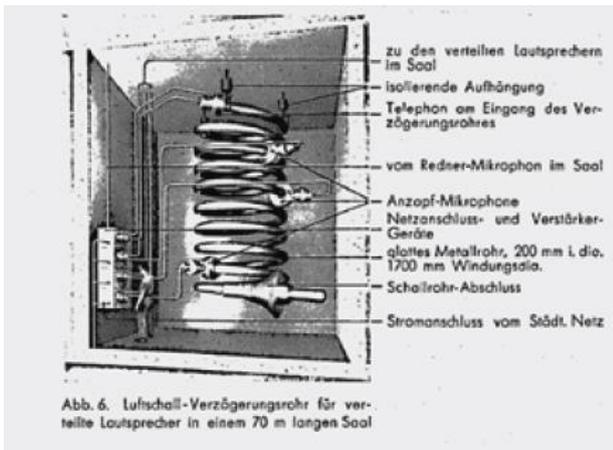


Figure 4 “Luftschall-Verzögerungsrohr“ by F. M. Osswald, 1937. Image: Empa Archive.

The decision was based on a statement by Paul Scherrer (1890-1969), Chairman of the Department of Mathematics and Physics. He grouped acoustics into “three clearly separate fields of research, which are never to be found in the same institute”² [6], namely electroacoustics, room acoustics/noise control and physiological acoustics. Scherrer thus interpreted the multiple references to other disciplines not as a potential, as Osswald once did, but as a disadvantage. Only with regard to electroacoustics did Scherrer

support Muri's proposal, but with considerable restrictions. In contrast to electroacoustics, Scherrer found little interest in research into room acoustics and noise control: “This is a field in which the theoretical issues are largely resolved, but in which the often very complicated practical situation requires a great deal of practical experience, and in which feeling plays an important role. This field is usually represented by a practical engineer; it offers little real scientific interest.”³[6]. The third field of research named by Scherrer, physiological acoustics, however, belonged in his opinion to a medical faculty. Ultimately, acoustics was never able to establish itself as an independent discipline at ETH. In 1958 Furrer became director of Radio Schweiz AG (telecommunications and air traffic control), but continued to teach at ETH. In addition to Furrer, the professors Heinrich Weber (1907-1997) and Eric Rathe (1931-2016; 1965-1997 private lecturer for electroacoustics, 1978 titular professor) should also be mentioned, who contributed to acoustics at ETH.

3. ESTABLISHMENT OF AN ACOUSTICS AND NOISE CONTROL DEPARTMENT AT EMPA

The establishment of the Laboratory for Acoustics and Noise Control (Abteilung Akustik und Lärmbekämpfung) at the then *Federal Materials Testing and Experimental Institute for Industry, Civil Engineering and Trade, EMPA* (today: *Swiss Federal Laboratories for Materials Science and Technology, Empa*) in 1961 is not directly related to the debates about a chair of acoustics at ETH. Rather, it was the result of the persistent efforts of the League against Noise (Liga gegen den Lärm), which was founded in 1956 by people affected by noise, experts and politicians, including many influential personalities. With its commitment against noise, the League was already campaigning for environmental issues at a time when the concept of ecology was completely unknown in politics [4]. In this way, the League also helped to raise the awareness of Swiss citizens about environmental issues. The mainly conservative environmental movement brought together an expert network of academics with strong political connections. The initial spark was a paper by Karl Oftinger (1909-1977), who was the first in Switzerland to present noise as a legal problem [7]. As Gallati wrote, Oftinger freed the issue of noise from its “double isolation; on the one hand, from a cultural-critical-elitist discussion that emphasised education for a quiet, thoughtful life, and on the other hand, from a technical-scientific approach to solving the problem, which was based on the attenuation of unwanted sound waves”⁴ [4]. The spark quickly spread to the political arena. After consultation in both chambers of the Swiss parliament (legisla-

tive), the extra-parliamentary "Expertenkommission für Lärmbekämpfung" was established. Its purpose was to submit proposals to the Federal Council (executive) on how and at what level measures of a legal or administrative nature should be taken to control noise. After lengthy work in sub-commissions, a report was published in 1963 [8], which influenced noise abatement in Switzerland until the 1980s and formed the basis for the noise legislation aspects of the Swiss Environmental Protection Act (1983) [9] and the Noise Abatement Ordinance (1986) [10].

Even before the commission's report was completed, a Laboratory for Acoustics and Noise Control was founded at Empa on 1 January 1961 as a research, testing and consulting unit, headed by Anselm Lauber (1920-1995). For "objective and also psychological reasons"⁵, the laboratory name was given the addition "Noise Control" at the last moment [11]. Comparable to Willi Furrer's standard work "Raum- und Bauakustik für Architekten" [12], whose title was supplemented with "Lärmabwehr" (noise control) in the 2nd and 3rd editions [13][14], it was also the problem of noise that legitimised acoustic research when the Acoustics Laboratory was founded.

The foundation of the acoustics laboratory at Empa coincided with Empa's move from Zurich to the new site in Dübendorf. The acoustics laboratories were among the first buildings on the site (Figure 5). On 26 March 1962 Lauber looked back on the first year. Six members of staff, including one of the first physics laboratory trainees in Switzerland, were intensively engaged in setting up the activities and equipping the laboratories. In the corresponding letter to the Empa director, Lauber wrote: "I also agree with you that we should use today's widespread noise psychosis and the spectre of noise (with a real background) to expand and consolidate the new section. There is certainly enough work to do"⁶ [15].

4. DEVELOPMENT OF ACOUSTICS AT ETH AND EMPA AFTER 1960

4.1 ETH

Although acoustics has never been able to establish itself as a separate discipline with its own chair or institute at ETH, various research projects have been completed with remarkable results. A systematic overview of these has not yet been drawn up. However, a list of Swiss doctoral theses in acoustics by Beat W. Hohmann, himself an ETH graduate, is currently being compiled. It covers a wide range of topics, from which a selection of theses from various ETH institutes is presented below.

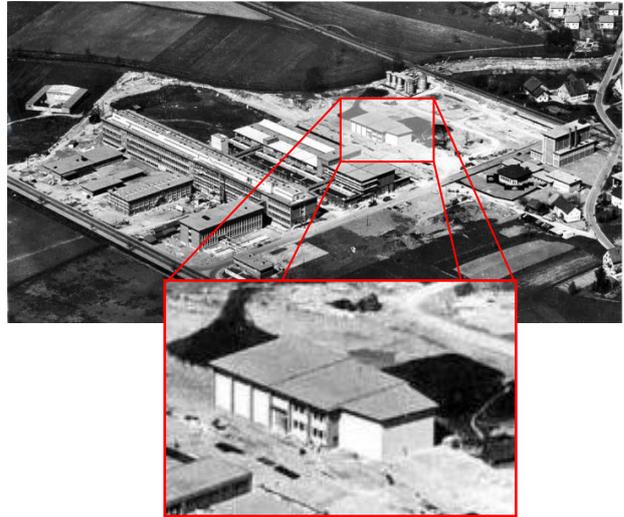


Figure 5 Empa buildings in 1962 showing the acoustics laboratory building (today SH1) with building acoustics laboratories (left) and reverberation chamber (right).

Let us start with a famous name: Jörg Sennheiser (*1944, Supervisory Board Sennheiser electronic GmbH & Co. KG, Honorary Professor Leibniz University Hanover). In 1974, he completed a PhD thesis at ETH in which he investigated the sound radiation of plates [16]. The PhD thesis of Eric Rathe, who later became a titular professor of acoustics at the ETH in 1960, on the use of transistors in communication equipment, is still on the periphery of acoustics [17], in contrast to his habilitation on the acoustic measurements on motor vehicles five years later [18]. It should also be mentioned that the ETH habilitation of his predecessor Willi Furrer dealt with the acoustics of radio studios [19]. Norbert Dillier's PhD thesis was about cochlear implants at a very early stage and he himself is still a leader in this field today [20]. Other PhD students worked in the field of hearing impairment, such as the above mentioned Beat W. Hohmann [21], who continued to work in this field throughout his professional career, and more generally on hearing [22][23] or the connection of perception of sound and vibrations [24]. Obviously, contrary to Prof. Scherrer's opinion presented above, it was possible to work on such topics at a technical university. Even contributions to research on noise effects can be found, e.g. on industrial noise [25] and sleep disturbances caused by noise [26], this also in a habilitation [27], there somewhat more broadly on noise effects in general. More obviously for a technical university, there are PhD theses focusing on technical acoustics, such as one on the acoustic localisation of

leaks [28], one on the acoustics in street canyons [29] and two on the squealing of railway curves [30][31]. There is even a thesis on musical instruments at ETH, which is also attributed to Empa [32]. Finally, the work on the history of acoustics from the Department of Architecture should be mentioned, on which most of this paper is based [1].

Lectures on acoustics have been and are still being given at ETH. In the past, the lecturers were the above-mentioned professors Osswald, Furrer and Rathe, but later other professors of ETH were also involved from time to time and finally, to a large extent, lectures were given from Empa staff (e.g. Acoustics I & II, Noise Abatement, Room Acoustics).

4.2 Empa

From its beginnings in 1961 until around 1990, the Laboratory for Acoustics/Noise Control, as a national centre of competence, not only carried out testing activities and independent expert assessments, but also made a number of internationally recognised research contributions, e.g. on aircraft noise, shooting noise and noise effects. It was an important partner for the authorities for the technical-scientific aspects of formulating and implementing noise protection legislation [9][10]. Examples of research results are the development of a at that time very advanced software for the simulation of aircraft noise on the basis of elaborate own source measurements [33] and contributions to noise effect research [34]–[36].

Since 1988 - and even more clearly since 2001 - Empa has concentrated on application-oriented cutting-edge research in material science and technology. As in 1944 at ETH, the scientific character of acoustics at Empa was questioned in this context in comparison with the excellence of the ETH Domain. Should the acoustics laboratory be closed, spun off or sold to an engineering company? Only after an extremely difficult process lasting several years was it possible to confirm the laboratory's place at Empa, where it now makes its contribution to research and the transfer of knowledge to society and industry, entirely in the spirit of Empa.

Over time, the excellent testing facilities, including high-level measurement technology, were further developed and expanded, for example with a platform for research on lightweight construction and an audio laboratory for listening tests (Figure 6). They were complemented by competences in modern calculation and simulation methods, which together with the outstanding experimental facilities result in an excellent research environment.



Figure 6 AuralLab at Empa: Auralisation, Visualisation

The following are just a few examples of noteworthy projects of the Laboratory for Acoustics/Noise Control:

- Development of methods for evaluation of noise effects and calculation of sound propagation, especially for aircraft noise [37][38] but also railway noise [39] and road traffic noise [40], finally also based on exact wave based methods [41].
- Research on noise effects and psychoacoustics, such as the development of noise assessment indices. [42][43] and listening tests on the annoyance caused by wind turbines. [44].
- Auralisation of environmental noise [45] such as from wind turbines [46][47], road traffic [48][49] and aircrafts [50][51]
- And finally, last but not least, in the field of materials science, Empa's core area: the development of materials and measurement as well as characterisation methods for acoustic materials in buildings [52]– [55], and the promising development of metamaterials like phononic crystals [56]–[58].

5. CONCLUSION

At ETH, the difficulty of establishing acoustics as separate discipline in an academic department has manifested itself clearly. However, the examples of PhD theses later carried out at ETH show that, contrary to the statements made in the mid-20th Century at ETH, a variety of topics in acoustics are worth exploring at a technical university. Of course, an institute or a chair for acoustics would still have been beneficial for the development of the discipline. Fortunately, however, a competence centre for acoustics was established

within the ETH Domain. The corresponding Laboratory for Acoustics/Noise Control at Empa today has an excellent international reputation.

6. ACKNOWLEDGMENT

We thank Beat Hohmann for sharing his not yet completed list of Swiss PhD theses related to acoustical sciences.

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¹ “sich der wissenschaftlichen Forschung entzieht, da sie hauptsächlich Fragen der praktischen Anwendung und der Empirie behandelt.”

² “deutlich drei ganz getrennte Forschungsrichtungen, die sozusagen nie am gleichen Institut bearbeitet werden.”

³ “Es handelt sich um ein Gebiet, bei dem die theoretischen Fragestellungen weitgehend geklärt sind, wo aber wegen der oft praktisch sehr komplizierten Sachlage grosse praktische Erfahrung nötig ist, und bei dem das Gefühlsmoment eine grosse Rolle spielt. Dieses Gebiet wird meist von einem praktisch arbeitenden Ingenieur vertreten; es bietet wenig wirklich wissenschaftliches Interesse.”

⁴ “... doppelten Isolation; einerseits aus einer kulturkritisch-elitären Diskussion, welche Erziehung zum ruhigen, bedächtigen Leben betonte, und andererseits aus einem technisch naturwissenschaftlichen Lösungsansatz, der auf der Eindämmung unerwünschter Schallwellen beruhte.”

⁵ “... aus sachlichen und auch psychologischen Gründen dürfte es zweckmässiger sein ...”

⁶ “Auch ich bin durchaus Ihrer Ansicht, dass wir die heute so verbreitete Lärmpsychose und das Lärmgespenst (mit realem Hintergrund) dazu benützen sollten, die neue Sektion A6 auszubauen und zu festigen. – Arbeit gibt es jedenfalls sicher genug.”



DEVELOPMENT OF ACOUSTIC RESEARCH AND ACTIVITIES IN ITALY IN THE LAST CENTURY

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ABSTRACT

The origin of Italian activities in acoustics in the last century are described, as they matched with the general research going on in physics and engineering in the country and abroad. The development of a specific institute devoted to acoustics within the National Council of Researches is reported with its branches developed from previously assessed research themes. Parallel activities developed in university or private companies follow, together with the contemporary collaborations stemming on international bases. The development of acoustical activities and the increase of researchers in the field stimulated the foundation of the National Association and the strengthening of international relations, with the active participation of Italian researchers to congresses and research institutions.

Keywords: *Corbino Institute, 17th ICA, ancient theatres acoustics*

1. INTRODUCTION

On the Opening ceremony of the 17th International Congress in Acoustics in the Michelangelo square on the Capitol hill in Rome, I happened to state that that was not the first acoustical event in that place, since more than two thousand years before another event did take place, that

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FIGURE 1. The geese quacking on the Capitol hill, on a marble relief found during excavations at ancient Ostia.

should have been really considered as the first in the field of acoustics in Italy [1]. On one night, indeed, of the year 390 B.C. the Gauls, that were besieging Rome, tried a last assault to the hill of the Capitol, but the geese sacred to Juno quacked loudly and their acoustic message alarmed the soldiers that were guarding the rock, thus saving the power of Rome. That ICA Congress dates Sept 2001 (A.D., of course!) and this citation seems to be properly chosen for signing the final point of this acoustics resumé of mine in Italy, not so much as for its initial coordinate. Indeed, the gap from 390 B.C. to the few first decades of the last century is plenty of musical events and musical theatres in the country and few medical developments took place which, however, were not continuously developed in organic research structures.

2. THE INSTITUTE OF ACOUSTICS

A breakthrough in acoustical research in Italy dates 1936 when the *Istituto Nazionale di Electroacustica* was officially founded as an autonomous center of researches within the National Council of Researches, whose name successively changed to *Istituto di Ultracustica "O.M.Corbino"* (1949) and *Istituto di Acustica "O.M.Corbino"* (1969), to be finally suppressed in 2018 and became a section of *Acoustics and sensors* within a larger *Istituto di Ingegneria del Mare*. The Institute establishment was strongly supported by Orso Mario Corbino, the professor of physics at the Rome University that formed the famous group of young physicists led by Enrico Fermi, its see being at the very same place where that group did work. The see at the historical place of via Panisperna - where the first nuclear reactions did take place in the garden fountain and that was to be abandoned in 1943 under the commands of the occupation troops - and the first director soon changed because of the war conditions at that time and Amedeo Giacomini, the new and former vice director, wrote [2] the first report in 1942 (listing 36 publications of the Institute personnel up to that moment), commenting about the general change that the research activities had undergone in the first half of the century, from single to group studies that needed to be supported by formal institutions, where to work in community formats. The electroacoustics theme derived from the previous experiences that both the first appointed and the first nominated directors, Sacerdote and Giacomini, respectively, performed at the *Galileo Ferraris Istituto Elettrotecnico Nazionale* in Turin and at the *Institut für Schwingungsforschung* in Berlin, and is clearly coherent with the very first facilities available at the Institute: mainly radio generators and power banks for acoustic transducers. An anechoic chamber and a reverberant one were also available.

Twenty years later, in the Sixties, the Institute annual report documented an activity in matter physics, that was to extend later into the area of solids structure and liquids absorption. In the former field there should be mentioned the discovery and successive works on internal friction in solids, what is now commonly called the Bordoni effect [3], named from the researcher working at the Institute at the time. With regard to the physics of liquids, innovative researches were done by D. Sette on the cavitation effects produced by power ultrasonics, while the initial work by A. Giacomini on the visualization of ultrasonic fields in liquids was continued with the use of coherent light in holographic techniques.

New fields of research were to flourish together with the enlargement of the Institute in the successive decades, including surface acoustic waves technologies and medical ultrasonics, together with the noise evaluation and abatement in industrial sites and street traffic.

It is interesting to mention that at the same time the Institute began to act at the international level [4]. In 1951 the *International Union of Pure and Applied Physics* (IUPAP) decided to create the International Commission on Acoustics (ICA) as one of its subcommittees [5], and A. Giacomini was one of its members, together with R.H. Bolt, F. Canac, F. Ingerslev, E. Meyer, W.M. West. One of the first questions the Commission was called to debate was one relative to regulate the succession of the congresses organized the year around. The year before the Commission foundation, a meeting on ultrasonics took place in Rome and two years later the International Congress on Electroacoustics in Delft opened the series of the ICA congresses on international scale. It may be interesting to report the presence of the papers at the conference from the various countries participating to it: Germany 19, USA 13, UK 15, Netherland 9, France 9, Denmark 5, Italy 4, Belgium 4, Austria 1, Finland 1, Norway 1, Sweden 1, Switzerland 1. Successively, a delegate from Italy was constantly member in the persons of D.Sette and the author. In 2001 the 17th ICA conference took place in Rome with 2000 participants [6].

3. ACOUSTICAL RESEARCH IN NATIONAL INSTITUTIONS

The *Istituto Elettrotecnico Nazionale* devoted to research in electrotechnics was founded in 1934 in Turin for the specific purpose to link the work of the university laboratories with the needs of the rising industry. Within its activities, metrology was a leading point, such as to give rise in 1968 to a new *Istituto di Metrologia*, dedicated to G.Colonnetti (from 2006 *Istituto Nazionale di Ricerca Metrologica*), where acoustics metrology was particularly cultivated. A sector was devoted to maintaining acoustics and ultrasonic calibration services, in participation with few international standard committees. From this area, there stemmed various researches on calibration procedures and technologies, as

well as on noise in working places, architectural acoustics and physical acoustics.

University research in acoustics found its natural growth in places where researchers from the above described institutions had had previous or successive experiences. At Trieste university a small group worked on acousto-optics and at the Perugia university a group was active, working on ultrasound in nonlinear and fractal materials and seismic vibrations; a line of research originated from the Bordoni group on solid state acoustics was also present. Sapienza university in Rome was a natural seat where several researchers from the Institute Corbino finally established, working on nonlinear acoustics and the Bordoni effect, and opened new lines on bioacoustics and medical acoustics, in addition to working on the audio frequencies range for characterization of microphones and building acoustics. At Ferrara and Bologna universities there have been lively groups active on the acoustics of ancient and modern halls and theatres and noise abatement and control, respectively. Similar fields of research were cultivated at Napoli, signing the general Italian interest for acoustics as cultivated and developed in ancient times. At Padova there were present activities in the field of phonology, at Milano of audiology, in Palermo of noise, in Firenze of architectural acoustics, in Messina of cavitation acoustics.



FIGURE 2. The cities where activity in acoustics was present in Italy in the last century.

It should be recalled that the main characterization of all the above mentioned activities, mainly connected with the two institutions founded in the Thirties, were in the fields of the physical acoustic, while noise research, as well as speech and architectural acoustic research, stemmed autonomously in few different places and

found a natural development within the acoustical association, that was founded as *Associazione Italiana di Acustica* (AIA) in 1972 [6]. At the international level, AIA very soon joined FASE and ICA and in 1992 was one of the 12 national associations to found the *European Acoustics Association*. In 1977 AIA started the publication of the national journal, *Rivista Italiana di Acustica*, still active today. By the end of the century AIA was structured in several thematic groups on environmental acoustics and musical acoustics, that were to proliferate in the years to follow.

A final comment should be also given on the acoustics legislation, just to recall that a final decree on noise control and pollution dates the end of last century (1997), while noise as a social problem disjoint from health problems was earlier considered (1984), with the establishment of a specific *Ministry of Environment*.

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THE DISSEMINATION OF ACOUSTICS IN ITALY HELD BY THE ITALIAN ACOUSTICAL ASSOCIATION SINCE THE LATE 20TH CENTURY

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ABSTRACT

This paper is a brief review of the activities undertaken by the Italian Acoustical Association (AIA) during the past fifty years, covering the main stages of a long journey involving many people. The annual national congress, started in 1973, is the common thread of the AIA's activities, to which many other meetings on specific topics have been added over the years. The publishing activity is built on the AIA's journal "Rivista Italiana di Acustica", founded in 1977, and includes also the proceedings of the AIA's congress and of the other meetings on specific topics.

The paper wishes to be not celebratory, but rather a tangible testimony of the efforts made by the AIA's members for the development and progress of acoustics in Italy since the late 20th century and for the cooperation between the Italian acoustic community and the international one. The growing presence of young acousticians in the AIA's initiatives in recent years bodes well for a prolific and successful future.

Keywords: *Italian Acoustical Association, activity timeline, diffusion of acoustics.*

1. INTRODUCTION

The Italian Acoustical Association (AIA) was founded on 10th February 1972, thanks to the farsighted initiative of 16 Italian acousticians. The promoter was Amedeo Giacomini,

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director of the Institute of Acoustics "O.M. Corbino" of the Italian National Research Council, who was the first AIA president. The other founders were from the University "La Sapienza" in Rome, the University of Perugia, the "Ugo Bordonini" Foundation in Rome and the National Electrotechnical Institute "G. Ferraris" in Turin.

As stated in its by-laws, AIA is a non-profit scientific association aimed to promote in Italy the study on acoustics in the research, standardization, industrial, professional and educational activities, as well as to increase the society awareness on acoustics.

In pursuing these objectives, AIA has carried out a wide activity throughout the past fifty years, including its annual national congress, seminars on specific topics, often organized by the AIA's Technical Groups, the AIA's journal "Rivista Italiana di Acustica" and, more recently, webinars at outreach level and for professional and training credits, as well as cooperation with other national and international associations.

2. THE ANNUAL NATIONAL CONGRESS AND SPECIALIZED MEETINGS

The first AIA annual national congress was held in Rome on May 1973. After that, the congress has been regularly organized every year and, so far, hosted in 32 cities distributed almost in all Italian regions. Sessions on traditional topics are usually attended by 180 participants, on average, during three days. This event is the main occasion for Italian acousticians to meet together and share not only their scientific and professional expertise, but even to strengthen their relationship, as happens during the social dinner. The general assembly of AIA members takes place during the congress and often, immediately before and/or after the congress, meetings on specific current topics are organized.



In addition to the technical and social activities, the congress program includes the award ceremony of the AIA prizes granted to the best degree (the Giacomini award) and PhD dissertations (the Sacerdote award) on acoustics by young people, as well as the best poster shown at the congress (the Barducci award).

The proceedings collect the texts of all the presented papers, sometimes in full or, more recently, in extended abstract version. They are regularly published with the International Standard Book Number ISBN code and represent an important reference for Italian acousticians, and also show the development of their activities over the years on all the topics of acoustics.

The AIA activity throughout the year is not limited to the national congress, but includes other meetings and events dedicated to specific topics, among the many phonetics and speech, classroom acoustics, environmental acoustics, noise and vibration in the working environment, building acoustics, industrial noise and vibrations, architectural acoustics, musical acoustics, bioacoustics, soundscape, acoustic materials, and so forth. These specialized meetings have been often organized by the AIA Technical Groups focused on specific topics, as reported in Tab. 1. These meetings have been often structured in invited papers and panel discussion and/or round table. Even for these events the proceedings have been published with the ISBN code and contribute to the dissemination of the knowledge on acoustics in Italy.

Table 1. The AIA's Technical Groups.

Acronym	Topic
GFS	Phonetics and speech
GAM	Musical acoustics
GAA	Environmental acoustics
GAE	Building acoustics
GAL	Noise and vibration in the working environment

3. PUBLISHING AND DISSEMINATION

In addition to the publication of the proceedings, in 1977 AIA started to publish its journal, named "Rivista Italiana di Acustica" RIA. The promoter was Italo Barducci, AIA president at that time.

The journal aims to promote and spread the knowledge of acoustics and to encourage the exchange of information between those who, in Italy or in foreign countries, study and work on this topic. To this end, the journal publishes review papers and tutorial by well-known specialists,

original research articles and technical notes. All texts are usually in Italian, although not excluding foreign languages, preferably English. A section is dedicated to news from AIA and other national and international acoustic associations, including a calendar of main scientific events. Over the years, the fields of interest have been expanded and diversified into scientific research articles, technological and innovative technical applications, review articles, technical notes, case studies and measurement campaigns, insights into the practical experiences, regulations and legislative implications of acoustics and its different applications.

All submitted papers are evaluated by a double blinded peer review process.

The journal, published with its International Standard Serial Number ISSN code, has been modified over the years to make it more efficient in dissemination and to increase the interest of readers. Thus, from the original print version, changed three times in the format and periodicity, nowadays the journal is available online under open access license and it is included in the Directory of Open Access Journals, a search engine linking more than 10,000 open journals in 134 countries, opening the RIA to a wide readership without any restrictions and payment.

All the articles published from 1977 up to 2011 are available in electronic version and indexed by author, topic and volumes.

3.1 Surfing the web

Since 2000, AIA is on the web with its domain to reach the greatest number of users and provide update information. The website is regularly renovated and maintained to implement a user-friendly interface and to assist in the management of administrative issues and the organization of the events, including the national congress.

At present, 30 visits and more than 210 pages visualized per day, 3200 registers users and more than 5000 documents downloaded prove the importance and the efficiency of this tool for dissemination. The AIA members have also access to the archive of the INCE-USA publications.

A section of the website is dedicated to the INAD-Italy activities, a group of AIA members organizing the International Noise Awareness Day in Italy to promote the awareness of the long-term noise exposure hazard and to counteract its effects both on hearing and, more generally, on public health. The event involves schools at different levels to educate children to sound and soundscape listening, jointly with other schools in the world.

Furthermore, the website has been an essential tool during the restrictions issued to limit the spread of COVID-19

pandemic that forced AIA to stop its activities in presence, like the national congress and other meetings. This notwithstanding, AIA has taken steps to implement new formats to continue its dissemination activities. Thus, from October 2020 webinars have been organized with an innovative and outreach approach, young speakers and duration limited to 1 hour at lunch break, to stimulate the interest and awareness of people on current topics in acoustics. This initiative has been very successful, more than 100 attendees on average at each webinar, and it has been extended to other webinars jointly organized with other national associations on topics of common interest. The recording of each webinar is also available on the AIA channel on YouTube.

Webinar of longer duration, usually half day, with traditional structure of lectures by invited speakers are also offered and, for some of these, professional and training credits are granted on request of attendees.

Among the several documents available in the website (e.g., the national congress proceedings), the AIA newsletter

provides update information to all the AIA members and registered users.

3.2 Social media and communication

In the efforts of being in steps with the evolving times and considering the role of social media played especially for young people, AIA is present on this communication tool to inform on its activities. At present there are 1000 followers on Facebook, 350 on Twitter and 1200 links on LinkedIn (with more than 200 like), with a potential readership of the news published on these media of more than 6,000 users.

Among the AIA followers on Twitter, there are the press offices of national and international public institutions on environmental protection, standardization bodies, professionals and associations of manufacturers, users and consumers.

Figure 1 reports a timeline of the broad range of the AIA activities carried out in these 50 years.



Figure 1. The timeline of the broad range of the AIA activities carried out in past 50 years.

4. INTERNATIONAL COOPERATION

In fulfilling its statutory objectives, AIA has been and is active at international level too. Indeed, in 1972, AIA was among the associations co-founding the Federation of Acoustical Societies of Europe (FASE). On behalf of this

institution, in 1981 AIA organized and hosted in Venice the 4th FASE Symposium on Acoustics and Speech.

Since 1972, AIA is member of the International Commission for Acoustics (ICA) and, on behalf of this institution, in 2001 organized and hosted in Rome the 17th International Congress on Acoustics.

In 1983 AIA joined the International Institute of Noise Control Engineering (I-INCE). In 1986 AIA, during its national congress in Sorrento, was twinned with the Sociedad Española de Acústica.

In 1992 AIA was among the 12 associations founding the European Acoustics Association (EAA) which replaced the FASE. On behalf of this institution, AIA has organized two congresses:

- in 2003 the 5th European Conference on Noise Control (Euronoise), hosted in Naples with the theme “The European challenge for a better sound environment”;
- in 2023, twenty years later, the 10th EAA Convention Forum Acusticum, hosted in Turin with the theme “Acoustics for a green world”, preceded by the EAA Summer School.

Furthermore, from 2008 to 2019 AIA had in charge the management of the EAA product “Documenta Acustica”.

In 2013 AIA jointly with the German Acoustical Society (Deutsche Gesellschaft für Akustik, DEGA) organized and hosted in Merano, Italy, the EAA Euroregio Conference and the EAA Winter School for young acousticians.

In 2011 AIA has signed an agreement with the International Institute of Acoustics and Vibration (IIAV) and, on behalf of this institution, has organized and hosted in 2015 in Florence the 22nd International Congress on Sound and Vibration (ICSV22).

Further international events, sponsored by the above organizations and organized on behalf of other institutions, have been carried out by AIA. Among these:

- in 1995 the 18th International Congress for Noise Abatement in Bologna, for the Association Internazionale Contre le Bruit (AICB);
- in 2007 the 11th International Conference on Hand-Arm Vibration in Bologna;
- in 2015 the symposium “The science of Acoustics serving the Food, the Nutrition and the Environment. From protection system to innovative technologies for agriculture and fisheries”, held in Milan within the EXPO 2015.

Some AIA members have been appointed of managerial positions in all the above organizations over the years.

Figure 2 outlines the main international events above mentioned.



Figure 2. The main international events organized by AIA.

5. CONCLUSIONS

This brief overview of the broad range of AIA activities does not want to be celebratory, but rather wishes to thank all its members who, voluntarily, by their valuable contributions

enable to go ahead with accomplishing the statutory objectives and make AIA a lively and exciting community, well connected with other national and international associations. The growing presence of young acousticians in the AIA initiatives bodes well for a prolific and successful future.

OVERVIEW OF HISTORICAL DEVELOPMENT OF ACOUSTICS IN PORTUGAL

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ABSTRACT

There is an apparent interest in identifying the genesis and the different historical moments in which knowledge is based. The result of complex processes that involve consent, conflicts, different types of mediation between various subjects and institutions, aims to understand its dynamics, continuities and discontinuities in the established evolutionary processes. The existence or development of prejudices, which can be considered to have been paradigmatic in relation to the development of a practice of Acoustics in Portugal, has initially created some constraints and difficulties, reflected for example in construction costs.

At former times, a sequence of stages occurred. They were felt as moments of marginality, with an inferior status, which were pointing out to a progressive acceptance, as the demands of comfort and environmental protection were gaining generalized recognition. Simultaneously, with accentuated technical and scientific evolution, stages of acceptance similar to those that generally occurred in more developed countries have emerged.

This paper focuses on the development and evolution of Acoustics in Portugal, mainly in its more relevant branches for the whole Society, presenting its first stages, its spread in research institutions and academia, and its importance for the whole community, as well as the links that have been established at international level.

Keywords: *Acoustics, Associations, Country, History.*

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1. INTRODUCTION

Acoustics is one of the most important disciplines we have nowadays to deal with the comfort and well-being of individuals and societies. It is a matter of concern for public authorities, for universities, for private sector, for developers and for the community as a whole. Its spread and inclusion in the curricula of academia had its beginning in the last century, becoming the matter more acute and relevant in the last half of the 20th century.

In Portugal, due to the awareness of population requiring better living and working conditions, the jump of its inclusion in the let's say more common world, (not just that confined to research or academia) was done in the last quarter of 20th century. Nowadays, the subsequent sustainable concept is a common matter in all branches of society.

2. PRESENTATION

Science can be seen as an attempt to communicate with nature, to establish a dialogue where questions and answers stand out. This description must be, obviously, completed in such way the man of science can be distinguished from the magician or the sorcerer and, at the furthest point, from the bacteria, which also interrogates the world around and tries to decipher the chemical and physical signals according to which they orient their actions.

Technology can also be described through the dialogue it creates and allows with nature, in which, however, the human intervention component is privileged, being dominated by efficiency and productivity criteria, from which, logically, similarities and differences with respect to fundamental science derive.

Sound emerges as an almost inevitable by-product of all activity. Nothing relevant happens without noise, and silence can thus be interpreted as a paradox. Sound is, in fact, an absent presence or a present absence, with possible associations with desires and terrors, hearing and representing a connection with something beyond the world of forms. Hearing is, according to the bibliographical references available, the first sense to awaken in the fetus, dominating amniotic life as a perception of a world in which it will live, with no possibility to “escape”: it is possible to close your eyes, but you cannot “close your ears” ...

Man is characterized as a species by his ability to think, that is, to process acquired knowledge and elaborate reasoning, thus creating a novel knowledge, surpassing infinitely oneself, an inner reflection at the level of the most advanced structures. Because it is difficult to understand whether, a thought does not have the support a language, and since verbal language is clearly privileged for man, it can be said, by the way of a synthetic definition of the species: Man speaks.

Acoustics emerges then as the branch of knowledge that deals directly with the preferential vehicle of communication of human thought, very close, therefore, to the essence of this thought. Touching on Aesthetics and the Arts through Music and Audio-visual Techniques, on the Human Sciences, on Biology, on Chemistry, on Physics, it reveals, a diagonal character, a special ability to unveil correlations between different areas of knowledge.

In Portugal, the development of knowledge in the scope of Acoustics, began essentially in the sense of applications, we would say, with a technological character that, without a healthy scientific base, very often led to failures, which evolved positively as a scientific base was established, currently considered perfectly through the undoubted consideration of Acoustics as a scientific discipline, along with its full consideration in the field of applications, therefore of technology.

3. SOME RELEVANT STEPS IN THE DEVELOPMENT OF ACOUSTIC APPLICATIONS IN PORTUGAL

In Portugal, in addition to some “early” examples – see, as a reference, in Fig.1 (acoustic study of Teatro of S. Miguel (in Azores, carried out using a model from the field of optics, in 1947 - the study of Acoustics only began to take place at

a higher level, and with a technological polarization, that is, interventions made essentially on the environmental arena, in particular the built environment, around the beginning of the last quarter of the last century

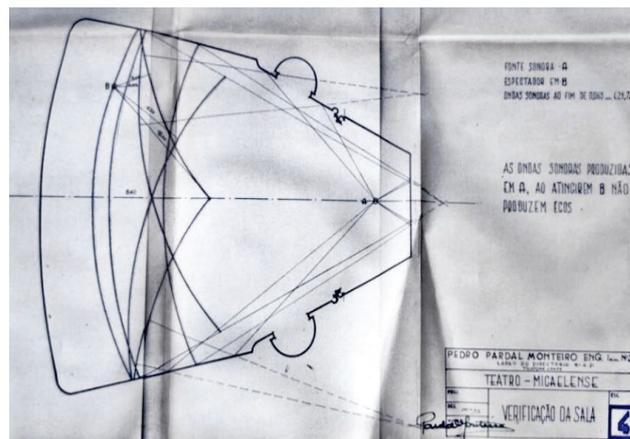


Figure 1. Aspect of the model of Azores Theatre

It should be pointed out that the first doctoral dissertation in the scope of Acoustics (by the main author of this work) took place, in Portugal, in 1975, having as theme the acoustic component of the environment. About ten years later, under the supervision of the author of this work, the teaching of Acoustics at a higher level began, as part of the degree in Technological Physics at the Faculty of Sciences in Lisbon, a graduation that covered the gap between Theoretical Physics, which is concerned with the analysis of models and development of methodologies for the study of physical phenomena, and Engineering, which applies to the establishment of appropriate solutions to technical problems.

The achievement of what we can refer to as a full “citizenship right” for Acoustics, was carried out through a strategy considering the three ways pointed out below.

- Structured grouping of technicians, from different backgrounds, who carried out, in a broad sense, activities in the field of Acoustics, strengthening awareness of this fact and thus creating a basis for group intervention in the country and possible connections abroad.
- Publication of national regulation that established criteria for the technical-scientific discipline of action, as well as the legal obligation to integrate the Acoustics

area in projects related to the various domains where this need arose.

- Legal establishment of the necessary and sufficient conditions for the exercise of the profession of designer in Acoustics, definitively ruling out those professionals, that although unprepared, tried to intervene.

Below, in summary of the ways in which these actions took place.

- I. Creation, at the end of the 1970s, of the Portuguese Acoustical Society (Sociedade Portuguesa de Acústica – SPA), in which the Professor Andrés Lara-Saenz, president of the Spanish Acoustical Society, played at the time an active role, after having been contacted in Madrid during the 9th International Congress on Acoustics (July 4-9, 1977), which he chaired. The importance of the creation of the Portuguese Acoustical Society is fundamental because it meant the awareness of professionals in the area and, consequently, the need/possibility of consolidating it in terms of social intervention. The first author of this paper was the President of its board, whom has been followed by Professor Bento Coelho and, later, by Professor Jorge Patrício, who currently holds the presidency of the Society and who gave it the international representation that it enjoys and which is focuses on forward.
- II. Development and legal publication of the “General Regulation on Noise”, the first Portuguese legal text specific to the area of applied acoustics, for whose development there were direct interventions by the President of the National Commission for the Environment, Engineer Correia da Cunha and the Secretary of State for Environment, Engineer Carlos Pimenta. This Regulation was approved by Decree-Law n° 251/87, published on the 24th of June, precisely the day on which the 5th Congress of the Federation of European Societies of Acoustics ended in Lisbon (22nd to 24th of June 1987), the first international meeting in the field of Acoustics held in Portugal. This regulation provided a technical-scientific basis for carrying out studies and from here the development of Acoustic Engineering began with an effective support. In 1989, this legal text was subjected to a small change being revoked in the year 2000, with a validity, therefore, of 13 years, from which the Noise Pollution Act was published. The legal frame was completed in 2002 with the publication of Building Acoustic code which has become an integral part of the construction licensing

process of housing buildings, and on applications in which the acoustic component of the environment has relevancy.

- III. Creation, on June 22nd, 2001, of the Specialization in Acoustic Engineering, with Engineer Francisco Sousa Soares being the Chairman of the Portuguese Order of Engineers (Ordem dos Engenheiros), who spared no effort to achieve this, because he had a clear notion of the need for this group – pointing out, of curiosity that, until then, those “who did” acoustic projects were from various origins. With the creation of the Specialization, whose first Coordinator was the author of this work, an area of Acoustic Engineering was established and a skill qualification mechanism was created to carry out studies in the area in question, the importance of which is evident.

In 2003, number 75 of the *Ordem dos Engenheiros* magazine was dedicated to Acoustics, realizing that at that time there were already twelve engineers specialized in Acoustics in Portugal. On March 19, 2004, organized by the Specialization, the First Journeys of Acoustic Engineering took place, being that a good indicator of its vitality.

In order to “penetrate”, in operational terms, the opacity of the real, Man resorts to the construction of models that, not constituting homothetic descriptions of the real, are ideal structures, thus freed from that opacity, constructed taking descriptors polarized in the variables considered as necessary for the type of intervention in question; the possibility of using models of progressive complexity can be put in analogy with the use of fishing nets with meshes of progressively reduced dimensions, meaning a progressively increasing approach to the real. A reference, obviously very superficial, to the activity carried out in Portugal about models in the field of Acoustics is of interest since they are the necessary tools for carrying out projects.

The first models used were analogue that is representations at reduced scale of the real works in study, using sound fields created by air jets or noise from electrical discharges, explored in multiple frequencies of the real ones, by factors equal to those of the reduction of the dimensions of the structure built. For historical reasons, a big dimension model is presented to study the propagation of noise in the vicinity of Lisbon airport, in order to protect a neighboring traffic lane (Fig. 2), in which the sound source (noise of electric discharges) has integrated a mask that gave it directionality properties consistent with those of jet propulsion aircraft and where, to take into account the

effect, on sound propagation, of deflectors of the jet engines installed in the field, nozzles were used blowing air in the proper direction and sense.

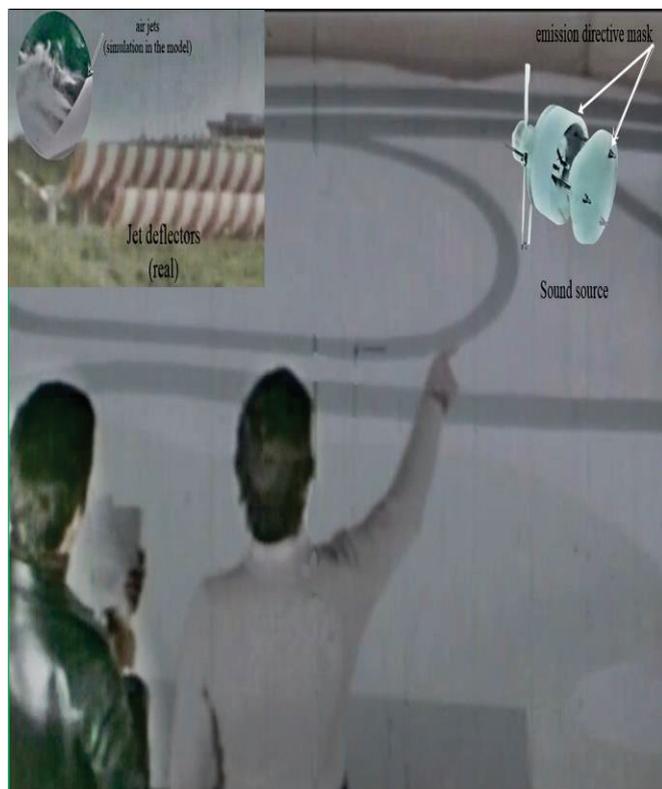


Figure 2. Model to study the propagation of aircraft noise in the vicinity of Lisbon Airport

Reference is also made to another situation concerning a high-capacity auditorium which, by express will of the Promoter, it was also the subject of analogue modelling, with a 1/40 scale mode (see Fig. 3). As it involves testing at a high range of frequencies, it was necessary to test it with desiccated air (3% relative humidity) in order to avoid the occurrence of increased absorption due to phenomena of relaxation of oxygen molecules, so the tests were carried out in the laboratory of Grenoble of the Centre Scientifique et Technique du Bâtiment. The model was built in Portugal, as well as a glass reverberant box, to test the materials to be used in the model, to present, for the different frequencies, absorption characteristics like those that the materials to be used in the construction of the real one presented for frequencies 40 times lower. The testing at Grenoble has been carried out by a Portuguese team.



Figure 3. Model at scale 1/40 of the audience part of the auditorium

Nowadays, as the modern computers allow easily the calculations implicated in digital models, these are the commonly used by Portuguese acoustic technicians— see, as illustration, Fig. 4

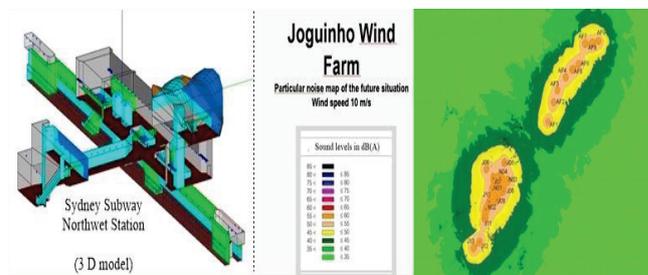


Figure 4. Model to study the propagation of aircraft noise in the vicinity of Lisbon Airport

4. PORTUGUESE ACOUSTICS IN THE WORLD

The Sociedade Portuguesa de Acústica (SPA) constitutes the uniting structure of Portuguese acousticians, in order to generate movements in the country, of technical-scientific training, and to facilitate the recognition, both in national territory and abroad, of the activity carried out by those that are dedicated to Acoustics in Portugal and also for those

who, despite not having this area as a fundamental subject of their activity, find in it aspects of interest and interrelationship with other subjects of knowledge that are important to deepen and develop.

SPA was created in the seventies of the last century. At the time, steps were taken to interest people linked to activities in the field of Acoustics and connections of an international nature were established. Among these connections, as previously mentioned, the Spanish Society of Acoustics deserves particular relevance, which led to the establishment of a privileged link between the two Societies: Portuguese and Spanish, which came to materialize in various initiatives, such as the one that led to the 1st Luso-Spanish Congress on Environmental Acoustics, which was followed by two others in the same series.

Currently, fully recognized, SPA is an effective member of the European Acoustics Association (EAA), the International Commission for Acoustics (ICA), the Ibero-American Federation of Acoustics (FIA) and the International Institute of Noise Control Engineering (I-INCE), in whose structures it has assumed relevant positions.

It should also be mentioned the involvement that SPA has in the normative field, since it is a Sectorial Standardization Organization, by delegation of the Portuguese Institute of Quality, representing Portugal in the European and ISO standardization committees (for example the CEN's Standardization Technical Committee).

It should also be pointed out that SPA assumed the Presidency of the Ibero-American Federation of Acoustics and the European Acoustics Association, materialized by the Chairman of the Board Doctor Jorge Patricio, which earned this Society an international recognition that will forever constitute a relevant component of its history, that is, the history of the development of the study and practice of Acoustics in Portugal.

5. CURRENT SITUATION IN THE COUNTRY

Nowadays, acoustics had spread all over the Country, bringing together multiple groups of engineers, companies, post-graduate courses, mainly in environmental acoustics and Building Acoustics, accredited laboratories to perform assessments, evaluations, tests on materials and construction solutions, promotion of good practices in

projects, constructions, assessments, standardization, etc. Acoustics is now a matter to deal with in environmental studies, in comfort in restaurants, quality of auditoria, theatres, and a strong motivation for students, professors, and community as a whole.

6. ACKNOWLEDGMENTS

The authors would like to thank all the colleagues who have contributed to this overall history, with the information they personally have and the “stories” they have been gone through.

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ON THE HISTORY OF THE SPANISH ACOUSTICAL SOCIETY (SEA)

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ABSTRACT

The Spanish Acoustical Society (Sociedad Española de Acústica, SEA) was founded in 1969 as a non-profit scientific and technical association whose primary goal is to promote the development of Acoustics in Spain.

Since its foundation, the SEA has maintained an intense activity aimed at promoting continuous progress in all fields of Acoustics, fostering Research and Development in the Science and Technology of Acoustics and its applications, and supporting and contributing with scientific and technical advice to the activities of the Administration, Companies, and Associations, seeking the improvement on acoustic environment, its control, and its influence on the welfare of the citizens.

This communication reviews the main milestones in the history of the SEA, its current situation, and its prospects..

Keywords: *Acoustical Associations, History of Acoustics, Sound.*

1. INTRODUCTION

The Spanish Acoustic Society -SEA- was officially registered on April 11, 1969, as a non-profit scientific and technical association in the Registry of Associations of the Ministry of the Interior of Spain. Throughout its more than fifty years, the SEA has been consolidating the exciting project born from the futuristic vision of a group of people who believed that Acoustics should have a great development in the society of future times and that with

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their activities Over the years the SEA has contributed to the development of Acoustics in Spain. Now is the time to recognize the work carried out by those enthusiastic founders in those early years, some of whom are still active in the SEA at this time, but, among all of them, it is necessary to highlight the figure of Andrés Lara, the first Spanish scientist who took a keen interest in Acoustics, and who, with his enthusiasm and dedication, forged what would be the future of the SEA. His contribution was essential for the rapid implementation and foreign recognition, because thanks to the prestige that Andrés Lara already had in the international acoustic fields, the trust of supranational organizations was achieved in a very short time for the organization of international events, such as the ICA congress in 1977 in Madrid, exactly eight years after the foundation of the SEA, a congress that would be held 30 years later, in 2007. Along with the figure of Andrés Lara, named Honorary President of the SEA in 1996 after 27 years as President, it is necessary to have an emotional memory for all those who throughout these years have made their efforts and efforts available to the SEA dedication, both from their positions as members of society or as members of the Governing Council. The progressive development of the SEA has been marked by the recognition of international organizations, from the extinct FASE to the ICA, EAA, FIA and I-INCE, which have relied on the SEA for the organization, on several occasions, of events of international congresses.

The SEA is a founding member of the Ibero-American Acoustics Federation -FIA- and the European Acoustics Association -EAA-, associations that together with the International Commission for Acoustics -ICA- are registered officially in Spain and with the social address in the SEA address.

The activities of the SEA have been reinforced in recent years with the development of actions of a diverse nature, such as congresses, conferences, symposiums, courses, etc.,



highlighting among them the TECNIACÚSTICAS have been maintained permanently since the first years of the associative journey. From these first moments comes the identifying symbol of the SEA, the "Caracola" designed during a Board meeting on a napkin by the famous architect Miguel Fisac, Vice President of SEA, who later also designed the figure of the "Caracola SEA" the maximum distinction granted by the SEA.

In the history of SEA, the relationship of the SEA with the Sociedade Portuguesa de Acústica -SPA- has a very special relevance since a mutual collaboration agreement was signed in the 90s, which made it possible for the TECNIACÚSTICAS to be held every four years in a Portuguese city, and to include the annual Luso-Spanish acoustic congresses and symposiums. This has allowed very fluid relations between Spanish and Portuguese acousticians, which has fostered both the presence of acousticians from both nations at each year's congresses, as well as the development of joint work between researchers from the acoustic departments of Portuguese and Spanish universities.

SEA has regularly published *Revista de Acústica*, the only acoustics magazine in Spanish, since the beginning, contributing to the dissemination of works by authors, both Spanish and foreign, in aspects that have to do with research, technology and the application of Acoustic science. Also, the online library, hosted on the SEA website www.sea-acustica.es, has incorporated lectures and papers from the different congresses held since the eighties of the last century, in which the SEA has been the organizer or co-organizer, and from the articles published in the *Revista de Acústica* since those same years, currently reaching a figure very close to 5,000 articles.

The contribution of the SEA to the improvement of the acoustic environment has materialized, among other actions, with the Noise Awareness Campaigns that we have promoted and, on many occasions developed directly, in schools, both primary and secondary schools. secondary and high school, with an estimated number of more than 200 centers benefiting from such campaigns, which has undoubtedly helped the new generations to learn ways to be more respectful of the sound environment. These actions have been complemented by the annual celebrations of International Noise Awareness Day, assuming by SEA from the very beginning, the promotion of that day in Spain with programs that have evolved over time, to establish themselves in the last 15 years. the celebration of this day in a secondary school, where its students are the protagonists of the activities of the commemorative act.

On the fiftieth anniversary of the SEA, it published the book "50 Years SEA 1969-2019" (*) developed and

composed by Antonio Calvo-Manzano, General Secretary of the SEA, this publication summarizes the history of these 50 years, also serving as a tribute to all the people who in various ways have contributed to building this history with their dedication to the SEA.

(*) The book "50 Years SEA 1969-2019" can be found on the SEA website www.sea-acustica.es.

2. THE EARLY TIMES

On the occasion of the First International Colloquium on Noise Control held in Madrid in 1967 and gathering the interest aroused among the participants of the Colloquium, it was decided to establish an Acoustics Association. The main promoters of this initiative were Andrés Lara, Director of the CSIC's "Leonardo Torres Quevedo" Center for Physical Research, later Institute of Acoustics, and Antonio Pérez-López of the Department of Acoustics "Torres Quevedo". Throughout the year 1968, the constitutional act of the Spanish Acoustic Society -SEA- was signed and the statutes were drawn up, later, once the administrative procedures for non-profit associations had been completed, the Spanish Ministry of the Interior approved the official registration of SEA in the Registry of Associations on April 11, 1969.

From the moment of its constitution, the Society has integrated a wide group of professionals related to the different fields of Acoustics, engineers, physicists, architects, doctors, audiologists, musicians, etc., and institutions, research centers, town halls, schools professionals, building and power generation companies, etc. Given the close relationship of the SEA with the CSIC's "Leonardo Torres Quevedo" the SEA's registered office was established in the "Torres Quevedo" address, which is still maintained today, and which is also the registered office of EAA, ICA and FIA.

The first colloquiums organized by the SEA were "The Acoustics of Rooms in Hearing and Sound Reproduction" in July 1969, and "Social Urban Noise Problem" in January 1970. That same year, in September 1970, the "First Spanish-British Symposium on Acoustic Environment", was chaired by Professors Stephens from Imperial College London and Lara from "Torres Quevedo".

In July 1970 it was held the "2nd Anglo-Spanish-Netherlands Symposium" at the Imperial College London. As a curious fact in this Symposium J. Pfretzschner and A. Calvo-Manzano presented the paper "The acoustics of the castanets", a typical Spanish musical instrument, the paper that was illustrated live by the famous soloist Lucero Tena.

3. 50 YEARS OF SEA

The decade of the 90s marked a new stage for the SEA with the celebration in 1994 of the 25th anniversary of SEA and the active participation of the SEA as a founding partner in the constitution of the Ibero-American Federation of Acoustics -FIA-, a federation that It brings together the acoustic societies of Latin American countries and Spain and Portugal, the Federation was officially registered in Spain.

Possibly due to the development of Acoustics in various Spanish universities and the appearance of working groups that would later give rise to the creation of various acoustic departments and laboratories, the SEA had a significant increase in members and activities.

In 1990, the Conference on Environmental Noise in the Urban Environment was held in Barcelona, organized by the SEA, and sponsored by the Barcelona Provincial Council and the City Council. In April 1991, the International Conference “Noise in large cities” was held in Madrid, organized by the Madrid City Council and SEA, with the participation of leading specialists from various countries. The Proceedings of the Conference were published in the book “Noise in the City: Management and Control”.

3.1 TECNIACÚSTICAS

Every year the SEA celebrates the Spanish Congress of Acoustics "TECNIACUSTICA" in different cities in Spain and from 1998 by agreement with the SPA every four years in a Portuguese city.

We list some locations of these TECNIACUSTICA congresses: Pamplona 1992; Valladolid 1993; Valencia 1994; A Coruña 1995; Barcelona 1996; Oviedo 1997; Lisbon 1998 together with the First Iberian Congress of Acoustics of SPA and SEA; Avila 1999.; etc.

Recently the TECNIACUSTICAS were in Cadiz 2018; Madrid 2019; Elche 2022, and this year 2023 will be held in Cuenca.

In parallel with the TECNIACUSTICAS, the corresponding EXPOACUSTICA exhibition was held.

4. EUROPEAN AND INTERNATIONAL CONGRESSES

4.1 ICA

The first international congress organized by the SEA and the Institute of Acoustics, CSIC, was the 9th INTERNATIONAL CONGRESS ON ACOUSTICS ICA'77 held in July 1977 with the participation of 1,480

acousticians from 40 countries who presented a total of 855 papers and 10 conferences. guests. The Congress was opened by H.M. The King of Spain Juan Carlos de Borbón, Honorary President of the Congress, Dr. Edgar A. G. Shaw, President of ICA, and Dr. Andrés Lara, President of SEA.

During the days of the congress, an exhibition of acoustic and vibration products and services was held in which 22 companies from the sector participated, occupying an area of 450 m2. Two satellite symposiums were held on ICA'77, one in Barcelona on “Sound Recording and Reproduction” and another in Seville on “Hearing and Industrial Noise Environments”.

During the ICA'77, twinning and fraternization ties were strengthened with the Portuguese acousticians who generated the following year in the First Luso-Spanish Symposium on Environmental Acoustics held at the National Civil Engineering Laboratory -LNEC - in Lisbon chaired by professors Pedro Martins da Silva and Andrés Lara. This twinning continues today with events and congresses organized jointly by the SEA and the Sociedade Portuguesa de Acústica SPA, highlighting the close relations that are maintained with the President of the -SPA- Prof. Jorge Patricio, the Board of Directors, and Portuguese colleagues.

Exactly 30 years after ICA'77, the 19th INTERNATIONAL CONGRESS ON ACOUSTICS ICA 2007 was held in Madrid in September 2007 with the motto “Acoustics for the 21st Century”. The Honorary Presidency of the Congress was held by H.M. King Juan Carlos I and the inaugural ceremony was attended by, among others, Prof. Philip A. Nelson, President of ICA, Dr. Carlos Martínez Alonso, President of the CSIC, Prof. Juan Antonio Gallego, President of the Congress. During the ceremony, the "CARACOLA SEA " was delivered to the CSIC for the support it has always provided to SEA, likewise, Prof. Andrés Lara, Honorary President of SEA, presented the "CARACOLA SEA " to Prof. Leo L. Beranek in recognition of his great contribution to Acoustics.

The participation in the Congress ICA'07 was 1,473 that have presented 1,078 oral communications and 219 posters in the 14 structured sessions. During the congress a Workshop on “Education in Noise Control Engineering” took place. Twenty-six firms participated in the EXPOACUSTICA'07 exhibition, presenting their most recent achievements in products, equipment, materials, and services related to acoustic technologies.

As part of ICA'07, two Specialized Symposiums were held, the ISMA 2007 – “International Symposium on Musical Acoustics” in Barcelona with the participation of 214 attendees from 25 countries, and the ISRA 2007

“International Symposium on Room Acoustics” in Seville, with 160 attendees from 35 countries.

4.2 FASE

In the 1980s, the European Acoustics Federation -FASE- that was the forerunner of the current EAA, maintained a very important activity by holding congresses, symposiums, and specialized conferences, thus in 1987 the SEA and the Institute of Acoustics, CSIC, organized the FASE Second Specialized Conference on “Acoustics and Ocean Bottom” with the participation of 49 experts, the Proceeding of the Conference was edited by Andrés Lara, then President of FASE. Subsequently, in June 1987, the Lisbon organized by SPA and SEA held the FASE Congress with the title “Advances in Physical Acoustics”.

In 1989, organized by SEA with the collaboration of various institutions, the "8th Symposium FASE on Environmental Acoustics" was held in Zaragoza and, in parallel, the TECNIACÚSTICA'89 Congress.

In October 2018, the X Ibero-American Acoustics Congress organized by the SEA, the University of Cadiz, and SPA was held at the School of Engineering of the University of Cadiz, as well as the 49th Spanish Congress on Acoustics -TECNIACUSTICA'18-. Throughout the three days of the congress, which was attended by 210 congressmen, 216 papers by 720 authors were presented, and presentations were distributed in 22 Structured Sessions. At the EXPOACUSTICA technical exhibition, 15 firms from the acoustics and vibrations sector were present. As is always customary in TECNIACÚSTICAS, at the end of the congress dinner, the traditional lottery of gifts donated by the exhibiting institutions and firms was held.

4.3 EAA

An important event at the beginning of the 21st century was the celebration in Seville of the EAA FORUM ACUSTICUM in September 2002, organized by SEA on behalf of the EAA and with the collaboration of the School of Architecture of Seville, the Institute of Construction of the University of Seville, the Institute of Acoustics, CSIC, and the Portuguese Society of Acoustics -SPA-. The Honorary Presidency of the Congress was the “Prince of Asturias Don Felipe de Borbón”. This event included the 3rd Iberian Congress on Acoustics, TECNIACÚSTICA 2002, and the European and Japanese Symposium on Acoustics.

In the FORUM 1,380 attendees participated, presenting a total of 660 conferences and papers in 17 technical sessions throughout the five days of the congress, and in and 22 exhibitors in the EXPOACUSTICA.

4.4 I-INCE

By agreement of the Board of the International Institute of Noise Control Engineering -I-INCE- the organization of the INTERNOISE 2019 congress was entrusted to the SEA and the congress was held in June 2019 at the Palacio Municipal de Congresos de Madrid, with the motto " Noise Control to improve the Environment". In IN'19, 1,188 experts from 50 countries participated, of which 278 were students and 894 papers were presented, 815 in oral format and 79 posters, work distributed in 17 technical sessions. 55 international firms participated in the technical exhibition. At the opening ceremony, the "CARACOLA SEA" was delivered to I-INCE, its President Marion Burgess and Past-President Joachim Schueren. Within the framework of IN'19, on the afternoon of June 18, the celebration of the "50th Anniversary of SEA" took place, an event that marks the long history of the Association since its creation in 1969. The "Andres Lara" that the SEA has established for young researchers, and the Prize of the "Luis de Camoens Chair" of the Carlos III University. The "Esencia Iberica" Ballet with its spectacular presentation put the finishing touch to the emotional act of celebrating the "5th Anniversary" of SEA.

5. FUTURE

After reaching fifty years of existence, the Spanish Acoustical Society -SEA- continues its journey and faces the development of new challenges to "Promote the progress of Acoustics" in accordance with Article 1 of its Statutes, promoting knowledge and promoting the dissemination of Acoustics in Spain with both scientific and technical activities, such as the Spanish Acoustics congresses -TECNIACUSTICAS-, Noise Awareness Campaigns in schools, International Noise Awareness Day, Word Hearing Day by WHO, conferences and colloquiums on specific topics.

In the strategic plan of SEA for the future, in addition to the activities at the national and Iberian levels with SPA, stand out in importance the relations with European and international institutions, EAA, ICA, FIA, I-INCE, IIAV.

6. MISCELLANY

6.1 SEA Awards

6.1.1 Caracola SEA

The highest distinction of the SEA to recognize the outstanding activities of personalities and institutions for

contribution to Acoustics is the "CARACOLA SEA", which was established in 1994 on the 25th Anniversary of the foundation of the SEA. The design "CARACOLA SEA" is a figure designed by the famous architect Miguel Fisac, SEA Vice President, who also designed the SEA logo.

6.1.2 Andrés Lara Award

In 2003, the SEA established the annual Andres Lara Award for young researchers who present a paper at the TECNIACUSTICA congress. The endowment of the Prize of 2,000 Euros is to collaborate so that the winner can participate in a national or international congress.

6.1.3 Luis de Camoens Award

Recently, the Luis Camoens Chair of the Carlos III University of Madrid awards the "LUIS DE CAMOENS" prize to young researchers who present their work at the TECNIACUSTICAS.

6.2 Publications

6.2.1 Revista de Acústica

The official publication of SEA is REVISTA DE ACUSTICA, the only journal in Spanish on acoustic. La Revista is currently published on paper and digitally and includes articles and news from the SEA, institutions, members, etc. The Magazine can be consulted on the SEA website: www.sea-acustica.es.

6.2.2 Books

To make current issues in acoustic science and technology available to the acoustic community throughout its long associative life, SEA has published several books, that it can be consulted on the SEA website: www.sea-acoustic.es.

6.3 Noise Awareness

The association has always been interested in Noise Control and, in addition to symposiums, congresses, and conferences, SEA dedicates part of its resources to Noise Awareness Campaigns in Primary and Secondary School Centers. The main activities in these Campaigns are the organization and development of the INTERNATIONAL NOISE AWARENESS DAY, conferences, theatrical performances of comics "Silin and Ruidon", theatrical performances, etc., in more than 200 schools over the years.

6.4 SEA Grants

SEA annually awards five grants to facilitate university graduate students to specialize in Acoustics and Noise Control in postgraduate and master's courses, the grants are 1,500 euros each. Likewise, SEA annually convenes five travel grants for participants in the TECNIACUSTICA congresses, these grants include the congress fees and 300 euros for travel expenses.

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DEVELOPMENT OF ELECTROACOUSTICS AT THE UNIVERSITY OF ZAGREB IN THE SECOND HALF OF THE 20TH CENTURY

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ABSTRACT

This paper presents the development of the scientific field of acoustics and electroacoustics at the University of Zagreb in the period that started with the establishment of the Department of Electroacoustics in 1954. Initially, the department was a part of the Faculty of Engineering, and from 1963 to the present it has been associated with the Faculty of Electrical Engineering. To this day, the department has been a unique and central institution on the territory of Croatia that covers research and teaching in many fields of acoustics. Over the years, scientific and professional activities undertaken by the members of the department influenced the development of certain branches of technology and industrial products, particularly in the fields of electroacoustic transducer technology and audiometry, but also in the design and evaluation procedures implemented in room acoustics, building acoustics and noise control. Many engineers, experts and scientists have received their education in this field through the great effort invested into the teaching activities by the department staff. In turn, this led to the launch of several companies that tackle everyday acoustic-related issues, but also to the development of both specialized and multidisciplinary research teams needed in various scientific projects that involve acoustics.

Keywords: *electroacoustics, audiometry, University of Zagreb*

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1. INTRODUCTION

It is not easy to concisely present the development of an entire research area during the 20th century within the University of Zagreb and Croatia in one paper. Many people have contributed to the development of this field. From the very beginning, it has been strongly linked to the development of the Department of Electroacoustics of the Faculty of Electrical Engineering and Computing, FER (formerly the Faculty of Electrical Engineering ETF) of the University of Zagreb. Credits must be given to Prof. Dr. Tihomil Jelaković as the founder of the department, and to his co-workers for their pioneering spirit, commitment to the field and productivity in terms of authorship and teaching. The aim of this paper is to present important moments and achievements that stem from the effort of the department staff invested in its development. The authors of this paper apologize in advance to all who will not be mentioned in this review, but who contributed significantly to the development of electroacoustics at the University of Zagreb.

2. HISTORICAL DEVELOPMENT OF THE DEPARTMENT OF ELECTROACOUSTICS

The Department of Electroacoustics was founded on October 1, 1954, as one of nine departments of what was then the Technical Faculty of the University of Zagreb. With the relocation of the Technical Faculty in 1959 to a new building, the Department expanded to a total of five rooms. This facilitated higher quality of scientific and teaching activities. Finally, in 1963, the Department of Electroacoustics moved to its present location, i.e. to the 10th floor of the then newly built building C of the Faculty of Electrical Engineering shown in Fig. 1. Thus, the department gained new laboratories, classrooms, and office spaces, occupying around 700 m² in total. The founder and the life-time head of the Department was Prof. Tihomil Jelaković. After his death in 1978, his



colleagues Prof. Miroslav Gregurić, Prof. Ivan Jelenčić, and Prof. Branko Somek continued working as teachers in the department, with the latter two alternating as heads of the department until their retirement at the turn of the 21st century.



Figure 1. Building B (the low-rise building) and building C (the skyscraper) of the Faculty of Electrical Engineering. The 10th floor of the skyscraper was given to the Department of Electroacoustics.

2.1 Prof. Tihomil Jelaković

University professor and engineer Prof. Dr. Tihomil Jelaković (1914-1978) is the most important person in the history of research in acoustics at the University of Zagreb. A fan of not only audible sound, but also ultrasound and infrasound, he dealt with the problems of recording, reproduction, processing, and transmission of sound, as well as the design of electronic devices.

He graduated in 1939 from the Technical Faculty in Zagreb. He worked as an engineer (1940-1952) in the studio equipment workshop at Radio Station Zagreb. Under his leadership, the workshop increased in space and staff, and in 1943 it had about 40 qualified workers. After World War II, in 1945, he founded the Laboratory for audio-frequency technology at Radio Station Zagreb and expanded the workshop shown in Fig. 2. Under his leadership it developed into the largest radio-engineering industry in Croatia at the time, i.e. the company called Radio Industry Zagreb (RIZ), with its experts and inventory as the core of the new company.

Therefore, Prof. Jelaković can be considered one of the founders of the electronic industry in Croatia.

Together with engineer Roman Galić, he translated the first books on the topic, written in German by W. Daudt: Radio Technique 1 and Radio Technique 2. The third book of this series, Radio Technique 3, focused on the field of electroacoustics and was translated solely by Prof. Jelaković. These translations of approximately one thousand pages in length represent the first literature in the field of electronics and electroacoustics available in Croatian. Prof. Jelaković was also one of the founders and editors of the magazine "Radio", first published in the fall of 1945. He was a contributor to the magazines Radio Technique, Electrotechnician and Electrotechnics. On his initiative, a school for technicians was founded at Radio Station Zagreb in 1947. Prof. Jelaković worked at that school as a teacher for five years and provided initial training for personnel of the Broadcasting Service of Croatia.

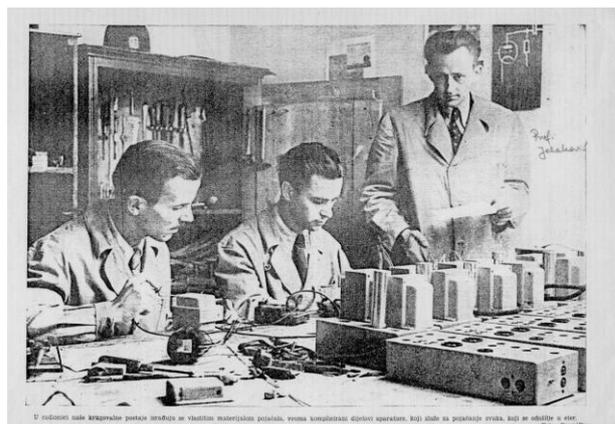


Figure 2. Prof. Jelaković (far right) and his co-workers design an audio amplifier in his workshop in 1948.

In 1951, Prof. Jelaković was elected assistant professor at the Technical Faculty in Zagreb, which developed into the Faculty of Electrical Engineering, where he became a full professor in 1962. At first, he taught a course called Electroacoustics to students majoring in the study program called Weak current, and a course called Weak current to students majoring in the Strong current study program. He recognized the need for continuous training of engineers due to the rapid development of electrical engineering. On his initiative, the Technical Faculty established the Department of Electroacoustics in 1954. He actively and significantly participated in the process of establishing an independent Faculty of Electrical Engineering in 1956.

He was the president of the Acoustical Society of Yugoslavia, and designed the first anechoic chamber in Yugoslavia, which was built in the Department of Electroacoustics.

As an associate of the Department of Phonetics of the Faculty of Philosophy in Zagreb, he designed and constructed several types of devices for the rehabilitation of people with hearing loss. This work is the result of his comprehensive knowledge of auditory acoustics and the experience gained in construction of sound studio devices.

Prof. Jelaković devoted his entire professional life to studying, teaching, and writing literature in the field of radio engineering and acoustics. As an author, he wrote seven books which were sold in more than 50,000 copies in thirteen editions in the period from 1952 to 1977. Almost all of them were pioneering works written for the first time in Croatian. These books are:

1. Transformers and Ballasts (1952)
2. Negative Reaction in Audio-Frequency Technology (1957)
3. Magnetic Sound Recording (1959)
4. Architectural Acoustics (first edition 1962; second edition, published under the title Sound, Hearing, Architectural Acoustics in 1978)
5. Introduction to Electrical Engineering and Electronics (1967)
6. Microphones (1969)
7. Transistor audio amplifiers (1973)

All these books have a monographic character, since they were written according to his original concept based on his own theoretical and practical experience. The covers of his books are shown in Fig. 3.



Figure 3. The covers of books written by Prof. Jelaković.

Prof. Jelaković was the leader of several scientific projects, and wrote many scientific papers, studies, and reports. As an excellent teacher who taught in a comprehensive, but easy-to-understand way with the emphasis on practical problems, he was very popular and loved by students.

2.2 Prof. Miroslav Gregurić

Prof. Dr. Miroslav Gregurić (1924-1990) worked at Radio Station Zagreb since 1948, and as a designer at RIZ since 1949. From 1952 he worked as a teacher at the Secondary Technical School in Zagreb. In 1962, he completed his habilitation and became an assistant professor at the Faculty of Electrical Engineering in Zagreb. He received his doctorate in 1972 and was elected associate professor in the same year.

At the undergraduate level, he taught the following courses: High-quality Technology Sound Reproduction, Receivers, Audiotechnics, Magnetic Sound Recording and Special Receivers. He taught Underwater Acoustics at the Faculty of Electrical and Mechanical Engineering in the city of Split, Croatia. He also taught some classes on audiometry at the Medical Faculty in Zagreb. His scientific work is largely associated with the field of hearing acoustics. He wrote the script Basic Electronics, and the textbook Radio Receiver Technique (two editions), shown in Fig. 4.

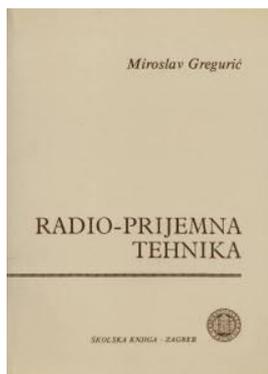


Figure 4. The cover of the book written by Prof. Gregurić.

As a research assistant, he designed various electroacoustic and other measuring instruments for application in laboratories. He designed devices for studio equipment. He worked in the field of measurements and protection against noise and vibrations, and tackled room acoustics problems. His principal field of interest was auditory acoustics and audiometry, where he was one of the leading experts in the country. The knowledge he gained contributed to the construction of several audiometers produced in the Department of Electroacoustics, as shown in Fig. 5. He created several electronic devices for medical diagnostics and rehabilitation. He designed and constructed several types of hearing rehabilitation devices. He collaborated with

domestic and foreign companies in this area of research (Ghetaldus, Wienaton, RIZ, Siemens).



Figure 5. An audiometry device designed and constructed at the Department of Electroacoustics.

2.3 Prof. Ivan Jelenčić

Prof. Dr. Ivan Jelenčić (1932-2016) completed all his education in Zagreb, graduating in 1959. He received his master's degree in 1971 and doctoral degree in 1976 at the Faculty of Electrical Engineering. From 1956 to 1966 he worked in RIZ, and in 1967 in the company Brown-Boveri as a construction engineer on the design of transmitters and receivers. From 1962 until his retirement in 2002, he worked as a teacher at the Department of Electroacoustics. Prof. Jelenčić is shown in a photograph in Fig. 6.



Figure 6. Prof. Jelenčić conducting measurements on electroacoustic devices at the department.

As a teacher, he taught the following courses: Acoustics and Electroacoustics, Audio-Frequency Techniques, Receivers, Digital Broadcasting and Multimedia Transmission, and Speakers and Sound Systems. Within the postgraduate study program, he taught Acoustic Design, Reception Technique in Digital Transmission and Electro-Mechanical-Acoustic Analogies.

He supervised many bachelor and master theses, as well as doctoral dissertations and worked in several research and professional projects at the department. He wrote many teaching materials, as well as his author book Loudspeakers shown in Fig. 7.

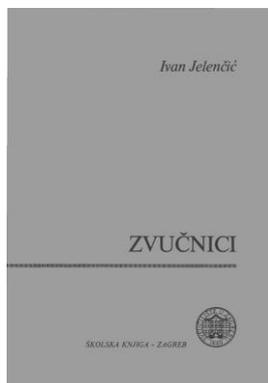


Figure 7. The cover of the book written by Prof. Jelenčić.

2.4 Prof. Branko Somek

Prof. Dr. Branko Somek (1931-) started his professional career in the RIZ company as an independent constructor of radio receivers in the electroacoustics department. After being elected as a permanent assistant at Faculty of Electrical Engineering at the Department of Electroacoustics in 1960, he continued working as an external associate, designer, and constructor in RIZ-IETA Institute, and later as a consultant at the RIZ-ELAK Factory. He received his doctorate in 1972 on the topic of infrasound. In 1974 he was elected full-time assistant professor and worked as a teacher at the department until his retirement in 2002.

In addition to studying electrical engineering, he was engaged in music, attending the music school (double bass), played in bands and orchestras, and recorded sound in radio and television production, as well as for record labels. He was also the leader of the music section at his faculty, as shown in Fig. 8.



Figure 8. The music section of the Faculty of Electrical Engineering under the leadership of prof. Branko Somek.

Prof. Somek was also a teacher of the course Musical Acoustics at the Academy of Music in Zagreb. He wrote the script Electroacoustics. He also worked on numerous professional projects in electroacoustics, room acoustics and acoustic measurements.

2.5 Prof. Momir Vujnović

Prof. Dr. Momir Vujnović (1931-2020) graduated from the Department of Electroacoustics in 1958. At first he worked at RIZ, and later in the Institute for Electrical Engineering Zagreb from 1959 to 1967, where he also worked in the field of audiometry and electroencephalography. He was also a part-time, and later full-time assistant at the Department of Electroacoustics from 1967 to 1982. He received his doctorate in 1977. In 1982, he was elected associate professor and worked at the department until his retirement in 1996.

He taught the courses Magnetic Registration, Music and Speech Acoustics, Noise and Vibrations in the master study program, and Auditory Acoustics in the postgraduate study program. He wrote several scripts in the field of electronics, acoustics, electroacoustics and tone frequency technology, as well as the books titled Oscillators, and Magnetic Recording of Signals, shown in Fig. 9.

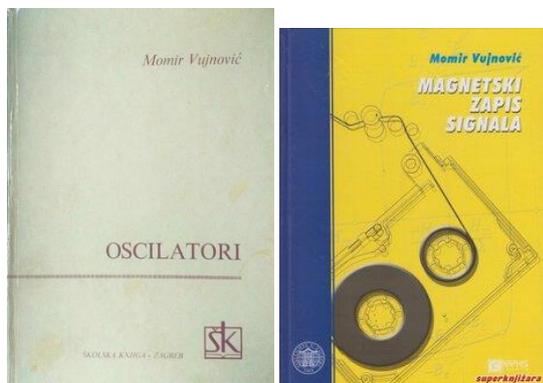


Figure 9. The covers of books written by Prof. Vujnović.

2.6 Other staff at the department

Over the course of almost 70 years since the founding of the Department of Electroacoustics, many colleagues were employed at the department as university teachers, research or teaching assistants, laboratory, and administrative staff. Due to space restrictions, only university teachers will be mentioned here, although all employed staff contributed a lot to the development of various branches of acoustics. The list includes all teachers (assistant, associate, and full professors) that were actively employed during the 20th century, as well as those who continue the legacy of the department in the 21st century until the present day. The years in the parenthesis indicate the period of employment:

- Tihomil Jelaković (1952 - 1978)
- Miroslav Gregurić (1955 - 1990)
- Branko Somek (1960 - 2002)
- Ivan Jelenčić (1962 - 2002)
- Momir Vujnović (1967 - 1996)
- Mladen Maletić (1970 - 2009)
- Bojan Ivančević (1980 - 2016)
- Hrvoje Domitrović (1991 - 2018)
- Siniša Fajt (1992 -)
- Ivan Đurek (1997 -)
- Kristian Jambrošić (1997 -)
- Antonio Petošić (2002 -)
- Marko Horvat (2002 -)
- Mía Suhanek (2007 -)

There are also other written and electronic teaching materials developed by department staff, such as the book Introduction to Hi-Fi Technique (1987) by prof. Ivančević, shown in Fig. 10.

The Department staff cooperated with other institutions at the University of Zagreb and beyond, almost since its

foundation. These are the Institute of Phonetics of the Faculty of Philosophy, Faculty of Mining, Geology and Petroleum, Faculty of Medicine, Academy of Music, all in Zagreb, and the Faculty of Mechanical Engineering and Shipbuilding in Split. Until 1991, the teachers from the department also taught at the Faculty of Electrical Engineering in Banja Luka, Bosnia and Herzegovina.

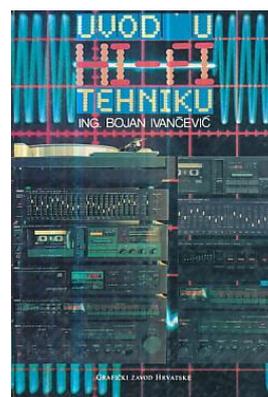


Figure 10. The cover of the book written by Prof. Ivančević.

3. TEACHING

The number of courses taught by the department staff has changed and increased over the years.

In the academic year 1959/60, the course Weak Current is taught to students majoring in the Strong current studies, and the courses Electroacoustics and Audio Engineering to students majoring in the Weak current studies.

In the academic year 1967/68, the courses Electroacoustics, Receivers, Audio Engineering, Spatial Acoustics and High-Quality Sound Reproduction Techniques are taught within the Electronics - Electrocommunication major. The department also participated in the postgraduate study, with the following courses taught at the postgraduate level: Electroacoustic Transducers, Magnetic Registration, Auditory Acoustics and Reception Technology.

By adopting the ETF-4 curriculum in the academic year 1978/79, the Department of Electroacoustics and the Department of High-Frequency Technology became the holders of the Radiocommunications and Professional Electronics major. The department staff teaches courses in two large groups: Acoustics and Electroacoustics, and Audio-Frequency and Receiver Electronics. Obligatory courses are Electroacoustics, Audio-Frequency Technique, Receivers and Magnetic Recording. Elective courses are Quality of Electroacoustic Systems, Professional Audio-

Frequency Devices, Special Receivers, Loudspeakers and Speaker Systems, Digital Audio Technology, Music and Speech Acoustics, Noise and Vibrations, Ultrasonic and Infrasound technology, Electroacoustics and Audiometry. Fig. 11 shows the middle generation of professors of the department.



Figure 11. (from left to right) Profs. Domitrović, Maletić, Ivančević and Fajt, correcting student written exams.

At the postgraduate level, the following courses were taught: Electroacoustic Transducers, Auditory Acoustics, Reception Technique, Electroacoustic - Mechanical Analogies, Theoretical Hydroacoustics, Hydroacoustic Transducers and Systems, Noise and Vibration Measurement.

4. DEPARTMENT EQUIPMENT

The successful development of the department and its teaching and research activities highly depended on the quality of specialized laboratory spaces and equipment procured by the department since its formation.

One of the most important rooms was the anechoic chamber built in 1963, shown in Fig. 12. Although quite small (net volume area of $2 \times 3 \times 2 \text{ m}^3$), it was the first one ever built in Croatia. As such, it was key to a lot of measurements performed on various electroacoustic devices.

Another important room used for many laboratory exercises, listening tests on loudspeakers, listening tests in general, etc. was the listening room that was acoustically treated and equipped with the necessary electroacoustic devices, as shown in Fig. 13.



Figure 12. The anechoic chamber in the department.



Figure 13. The listening room in the department.

The process of equipping the department with the necessary instruments began with self-construction of measurement systems: electronic voltmeters, oscilloscopes, phase meters, oscillators, voltage stabilizers, amplifiers, speaker systems, audiometers, sound meters, etc. In the beginning, instruments were borrowed from RIZ, radio and TV stations, and Jugoton record label. Generations of students were educated on these devices. The procurement of industry-manufactured instruments increased gradually, with instruments procured from companies such as Iskra, Siemens, Grundig, Philips, Hewlett & Packard, Tektronix, Rhode & Schwartz, etc. The first major step was the procurement of acoustic measurement equipment from Bruel & Kjaer. In this process, sound meters, analyzers, printers, microphone calibrators, measuring microphones, accelerometers, artificial heads, artificial ears, etc. were acquired, some of which are shown in Fig. 14.

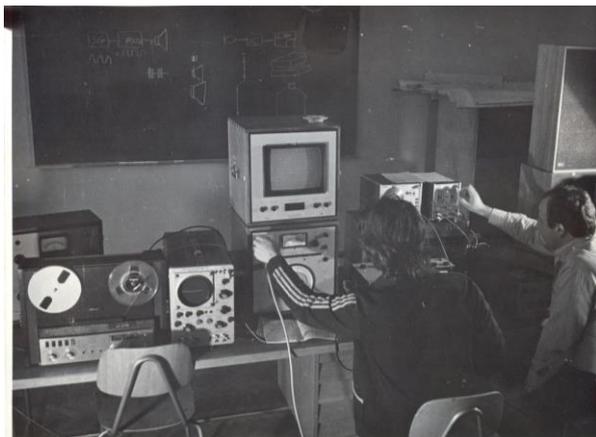


Figure 14. Measurements of the quality of electroacoustic equipment performed in the department.

The next major equipment procurement was in 1991, when the department received the first personal computers and modern acoustic equipment, such as digital sound level meter from Bruel & Kjaer, and other measurement devices from Techron TEF, Nagra-Kudelsky, AKG, AudioPrecision, etc.

The main sources of funding have always been the scientific and industry projects led by members of the department. In this way, the measuring equipment is constantly kept up to date, which makes it possible to carry out all kinds of acoustic and audio measurements according to international standards.

5. CONCLUSIONS

The Department of Electroacoustics has always served as a beacon of acoustics and the source of knowledge in this diverse field on the territory of Croatia and beyond, ever since it was founded almost seventy years ago. During this time, four generations of teachers have worked in the department and helped make it what it is today, starting with its founders as the “great-grandfathers” to us all. The senior teachers, now retired or deceased, have been the driving force of the development of the department all through the 20th century. The younger generations have taken over in the 21st century and have actively worked ever since to carry on the legacy of their elders, for many more successful years to come.

6. ACKNOWLEDGMENTS

The authors feel deeply thankful and would like to express their sincere gratitude not only to the founders of the Department of Electroacoustics, but also to all those who have contributed to the continuous development of the department and the field of acoustics in Croatia over the past seventy years.

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MODERN HISTORY OF ACOUSTICS IN GREECE

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ABSTRACT

Greece has a long tradition in acoustics. Already in the ancient era, the necessity for social gathering and cultural performance in the open air with optimum hearing and appreciation conditions, led the engineers of that time, to study and design theaters, conservatories and other public gathering places with excellent acoustic characteristics.

In the modern era, the acoustic community in Greece is also flourishing, assisted by the close collaboration between industry, universities, and research centers.

The Hellenic Institute of Acoustics (HELINA) is the scientific society of Greek acousticians. HELINA is a very active community, continuously growing in parallel with the continuous evolution of the Greek acousticians and of the acoustic education in Greece. HELINA and Greek acousticians play an important role in international acoustic affairs in both research and administrative issues.

Keywords: *History of Acoustics, Acoustical Education, Acoustical Societies, Greece*

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1. INTRODUCTION

Greek acousticians form a very active scientific community in Greece. The acoustic tradition in Greece started in the ancient era, mainly during the classic times when Greek engineers managed to design and construct theaters and odeia, with excellent acoustic characteristics.

The tradition of the Greeks in acoustics continued in the 20th century, assisted by the introduction of acoustic education as a special field in Greek universities. Thus, a new generation of acousticians was created with interests, specialization and activities in various areas of acoustics. Along with their colleagues who received their education abroad, consist now the society of Greek acousticians who have considerable contributions to basic and applied research on acoustics, as well as to engineering applications that include among others, the design of buildings characterized by acoustics of high standards, the design and implementation of noise-control solutions, the design and production of sophisticated material and electroacoustic systems for the enhancement of the acoustic characteristics of the areas requiring optimum appreciation of sound.

This article presents a short review of the history of acoustics in Greece with emphasis to the acoustic education and the activities of the Greek acousticians in modern era. A major part of this presentation is devoted to the Hellenic Institute of Acoustics (HELINA), which is the scientific society of acousticians in Greece. HELINA is very active with many contributions to the national and international acoustics.



2. ACOUSTICS AND ANCIENT GREECE

An inherent part of the ancient Greek civilization was the social gatherings and cultural performances. Social gatherings were held in areas called “agora” (αγορά) while cultural performances were held in open theatres of large size and/or special smaller conservatories (odeia – οδεία). The necessity for a clear appreciation of the speakers or the artists dictated the Greek engineers to study the acoustics of these areas trying to achieve the best possible result. They had to take into account orientation of the building, typical weather conditions in the area, capacity and additional characteristics of the places under consideration and find optimal solutions for the architectural design and the material to be used which included reflecting material such as marble and stone. The result of their studies was the construction of buildings with excellent acoustic characteristics. The acoustics of ancient theatres and odeia remain notorious until today. In addition, in order to achieve optimal appreciation of the dialogues during theatrical performances, especially for audience members in the distant seats, the ancient Greeks introduced the use of special masks that actors should wear during their performance. Thus, the masks had the role of a small loudspeaker.

As additional means to enhance the acoustics of ancient theaters, ancient Greeks and Romans used sound vessels, known as echea (ηχεία) resonators, a term introduced by the Roman architect Marcus Vitruvius Polo. A characteristic example of a Greek ancient theatre, equipped with echea was the theatre of the city of Lyttus in Crete. The acoustics of this theatre, which does not exist anymore, was studied by means of simulation techniques, by Polychronopoulos et al. and they showed that it was similar to that of the famous theatre of Epidaurus [1].

The use of these vessels continued in Greek Orthodox churches that were built, in the late Byzantine era and even beyond. It is noticeable that the acoustics of Greek Orthodox churches has always been an important issue for the architects as the necessity of clear appreciation of the Liturgy and the words of the hymns and sermons [2,3]

It is interesting to note that the issue of noise control was well known at least to the citizens of the Greek city of Sybaris. Sybaris founded in 720 BC was an important city

of Magna Graecia. It was situated in modern Calabria, in southern Italy [4].¹

According to Athenaeus [5], Sybarites (the citizens of Sybaris) were the first people to forbid those who practice noisy arts from dwelling in their city; such as braziers, and smiths, and carpenters, and men of similar trades; providing that their slumbers should always be undisturbed. And it used to be unlawful to rear a cock in their city. Sybarites were notorious for their sense of well-being, so noise control was probably of high priority for them.

It can be inferred from above historical data and by many other witnesses that acoustics was one of the areas of primary interest for Greek engineers in the ancient era. The tradition of Greeks involvement in acoustics is continued in the modern times.

3. ACOUSTIC EDUCATION IN GREECE

Acoustics as a distinct area of university education was introduced to Greek universities in the 20th century. Topics on acoustics began to be taught mainly in the Departments of Architecture of the National Technical University of Athens and the Aristotle University of Thessaloniki, indicating in this way the continuation of the tradition that wants Greeks to be particularly sensitive to building acoustics. Later on, topics on acoustics related to electronic and mechanical engineering were offered in underwater programs of Engineering and Science schools, while topics on acoustics were also introduced in programs of musical studies. In addition, physical acoustics, and computational acoustics were among the courses that were very popular among the students of Science Schools. No complete programs on acoustics in undergraduate or post-graduate level were organized in universities until the end of the previous century. The lack of specialized programs however didn't hinder students to get an enthusiasm in acoustics and proceed with studies and research at a graduate or doctoral level either in Greece or abroad thus strengthening the potential of Greek acousticians.

The first specialized departments on acoustics were established in the Technological Institutes of Crete and of the Ionian Islands, in late 90's. The department in Crete was on Music Technology and Acoustics, while that of the Ionian was on Sound Technology and Musical Instruments. On 2018 the Technological Institutes evolved into

¹ We are grateful to Walter Alfredo Montano (Argentina) for giving us the information on Sybaris.

Universities and the Department in Crete continues with the original name under the Hellenic Mediterranean University, while that of the University of the Ionian was merged with the department of Ethnomusicology, still offering courses on sound technology. The department of Music Technology and Acoustics of the Hellenic Mediterranean University is the only department in Greece specialized in acoustics.

Nevertheless, nowadays, many courses on acoustics are offered in most of the Greek universities that include the Universities of Athens, Thessaloniki, Crete, Patras, Thrace, Thessaly, Ionian Islands and West Attica as well as the National Technical University of Athens. In all these universities topics on acoustics are taught at both undergraduate and post-graduate level and the number of Master and Doctoral theses on the various areas of acoustics is continuously increasing. It should be added that many laboratories, offering sophisticated infrastructure for acoustic experiments (including underwater) have been organized in most major universities and associated research centers. These laboratories combine education with research and development enabling the design and implementation of acoustic innovative solutions. Most of the acoustic laboratories collaborate with the industry, ensuring the link between, education, research and production.

4. GREEK ACOUSTICIANS

In the decade of 90s, a modern framework of standards and specifications for building acoustics, traffic noise, noise and vibration control in workplaces and for acoustical measurements was adopted in Greece. At the same time, a plethora of special buildings (Music Halls, Theaters, Airports) and national highways were constructed within EC projects or by state funding. As a result, there was a great need of experienced people able to implement the new standards. During this period, Greek acousticians worked as consultants to construction companies and played a key role to the construction of high-performance buildings and to the control of environmental noise. As an example of this project the acoustics of Major Concert Halls in Greece (Athens, Thessaloniki, Patras, Heraklion) and Cyprus (Nicosia) have been designed by Greek acousticians and the solutions adopted were implemented in collaboration with Greek companies. The result is superb.

Great progress and know-how were also achieved in the field of Environmental Noise control. Noise was monitored for long periods of time in major highways, airports and cities and noise maps were constructed for the first time in

Greece. Based on noise maps, noise control measures were proposed and constructed (noise barriers, traffic regulations, quiet pavements).

To support all this activity, some Greek industries became active and in collaboration with University Labs developed acoustic materials (absorbers, elastic laminates, sound-insulating elements) and acoustical devices (noise barriers, anti-vibration springs, and mufflers). Both parts benefited from this collaboration a lot. Acousticians became experienced in applications while industry and constructors became familiar with acoustical specifications and developed the necessary technology to achieve optimal solutions.

In addition, Greek acousticians were involved in the research for underwater acoustics in collaboration with the Greek Navy but also in the framework of European projects dealing with marine science and technology. The team of underwater acoustics of the Foundation for Research and Technology-Hellas (FORTH) soon became famous for their contribution in the underwater acoustic research and, as it will be mentioned in section 6, it became by invitation the nucleus of the Hellenic Institute of Acoustics and the first Greek member of the European Acoustics Association.

The activities, of the Greek acousticians today, cover a wide range of topics including Building and Architectural Acoustics, Signal Processing, Underwater Acoustics, Ultrasonics, Musical Acoustics, Electroacoustics, Psychoacoustics, Computational Acoustics, Noise and Vibration Control, Physical Acoustics, Education and Acoustics.

5. ACOUSTICAL SOCIETY OF GREECE

In the mid 70's the persons working in different fields of acoustics in Greece reached a critical number. It was the right moment for the formation of a scientific society related to acoustics and as a result, the Greek Acoustical Society was formed. The members of the society as well as its actions increased. It organized the annual conferences on acoustics, joint conferences with other societies and seminars on special topics. The main achievement, however, was the creation of technical committees which prepared and proposed norms and technical specifications for several fields including building acoustics, noise and vibration control and acoustical measurements. This enabled the construction of special buildings (music halls, theatres, airports) and environmental actions in Greece,

considering acoustical specifications. As a result, acoustical industry, production and consulting benefited a lot. Despite the initial enthusiasm and its achievements, the Greek Acoustical Society failed to achieve further growth and to reconsider its aims and actions. After a period of inactivity, a descended course followed and finally the Greek Acoustical Society suspended its operation. However, most of its members were determined to continue their efforts to work towards a new Greek Acoustical Society and became members of the newly formed Hellenic Institute of Acoustics.

6. THE HELLENIC INSTITUTE OF ACOUSTICS (HELINA)

6.1 History

In 1999, the European Acoustics Association (EAA) was in a development stage. The Board of EAA wanted to add in its membership as many acoustical societies as possible from European countries with long tradition in acoustics but also from countries with an obvious potential in acoustic research and consultancy. The underwater acoustics group of FORTH had already become known to European acousticians and the Board invited the group to the EAA General Assembly held in Berlin that year. The group was represented by Prof. Michael Taroudakis who informed EAA that there have been initial discussions for the creation of a new Acoustical Society in Greece that could be accepted as a full member of EAA. The underwater acoustics group of FORTH was provisionally accepted as associate member of EAA.

At the same time, the conditions for the creation of a new Society in Greece were mature. All started after some meetings of an initiative group of few persons interested in acoustics that included mainly University Professors, Researchers, and officers of the Greek Navy. The outcome of these meetings was that the activities in the field of acoustics need to be further developed within an organized environment of a new scientific society. The initiative group adopted the title “Hellenic Institute of Acoustics” (HELINA) so as not to be confused with the old and inactive Acoustical Society of Greece.

Aiming at fostering the interdisciplinary nature of acoustics it was decided to allow participation of candidate members related to acoustics, coming from varying background and interests without meaningless restrictions protecting at the same time the scientific profile of the Institute. In that vein, the initiative group

appealed to people related to acoustics and informed them about an open organizational meeting which was to be held soon. Thus, HELINA was founded as a non-profit scientific association.

The founding assembly of the new Society was held in 2001. Prof A. Trochidis was elected as the first President of HELINA.

The creation of the HELINA was announced to the EAA officials during EURONOISE 2001 that was held in Patras (GR). The same year, HELINA was accepted by EAA as a full member and M. Taroudakis attended the General Assembly that was held in Rome representing the newly established HELINA.

The (initial) founding members of HELINA were mostly coming from academia and only few from industry. The profile of the Institute, however, changed over the years and now the members come from different backgrounds and interests and include engineers, physicists, architects, musicians, physiologists, psychologists etc.

The headquarters of HELINA, which were initially set in Athens, were moved to Heraklion (Crete) following the decision of the HELINA General Assembly held in 2006.

HELINA joined the International Commission for Acoustics (ICA) in 2012 and is a very active member of both EAA and ICA.

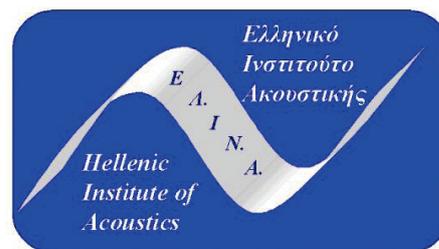


Figure 1. The logo of HELINA

6.2 Objectives

Looking back there is a number of reasons why the idea for a new society of acoustics emerged at that particular time. Active persons and groups in many fields of acoustics already existed mainly in the Greek Universities as well as in industry and administration. All these people were trying to find a way to come together to exchange experiences and

find appropriate solutions to their problems. Furthermore, the need to interact with members of other European acoustical societies and benefit from their experience was obvious.

Based on the above reasoning, the central aims of HELINA are:

- To diffuse and promote scientific knowledge and applications in acoustics.
- To promote collaboration between members from different acoustical background.
- To encourage the interdisciplinary collaboration between acousticians and people coming from different sciences.
- To support education in acoustics on both undergraduate and graduate level.
- To establish scientific relations with international acoustic associations.

6.3 HELINA activities

HELINA organize the National Conference on Acoustics every second year. The National Conferences were held in Patras (2002, 2018), Thessaloniki (2004, 2014, 2022), Heraklion (2006), Xanthi (2008), Athens (2010), Corfu (2012), Piraeus (2016). The Conference that was supposed to be held in 2020 was cancelled due to the pandemic.

The Conferences are attended by acousticians of both the educational/research and commercial sector. It is interesting to note that the number of papers presented in the conferences is continuously increasing and a significant part of the presentations are from graduate students or young acousticians, which is an indication of the continuous interest of the young scientists in acoustics.

In addition to the National Conferences, HELINA has organized international Symposia or Conferences on acoustics. The largest among them was EURONOISE 2018 held in Hersonissos, Crete. Prof. Michael Taroudakis was the chairman of the Conference. It was attended by almost 800 acousticians. EURONOISE is one of the EAA projects.

The Acoustics of Ancient Theatres Conference was another initiative of HELINA. It was organized under the auspices of the EAA in Patras (2012) and was attended by more than 100 acousticians. Prof John Mourtzopoulos was the chairman of the Conference. Presentations made during the Conference formed a special issue of the official journal of

EAA, which at that time was “Acta Acustica united with Acustica”. In 2022 a second edition of the Conference on the Acoustics of Ancient Theatres was organized in Verona (IT) by the Italian Acoustics Association (AIA) in collaboration with HELINA.

HELINA organize regularly workshops and seminars in various aspects of acoustics addressed to both young and experienced acousticians. Also their committees make suggestions for the state legislation in acoustic design and noise control.

Participation of HELINA members in press and information media is continuous, bringing to a greater audience the message that acoustics is a very important scientific area and sound is very important for our lives.

6.4 International contributions

HELINA is very active in all international fora related to acoustics. It has a continuous participation in the EAA and ICA General Assemblies. In recognition of this contribution to International acoustics, Prof. Michael Taroudakis, representing HELINA was elected President of EAA for the term 2013-2016 and President of ICA for the term 2016-2019, remaining in ICA Board as past President for the term 2019-2022. Under this capacity Michael Taroudakis was co-coordinator of the International Year of Sound 2020-2021. Thus, HELINA was present in all major international activities on acoustics.

7. DISCUSSION

The future of the acoustical research, industry and production is looking bright and within the next two decades we will see tremendous changes and achievements. On the other hand, HELINA completed more than 20 years of life. The number of members increase and a high degree of maturity was accomplished. It is the right time to reconsider its aims, its administration and its strategic planning.

The future of HELINA depends on its ability to deal with the incoming challenges. To address and promote emerging special topics new planning and actions are needed. One of the central objectives is to support the new generation of acousticians working on cutting-edge topics. One action is to organize and sponsor small workshops and symposia dedicated to special, innovative fields. Further actions could include prizes for young members with extraordinary

achievements and fellowships for young acousticians to promote excellence.

Most of the members of HELINA are coming from academia. Thus, they could substantially contribute to the improvement of the acoustic education in Greece. A committee could be formed to discuss the existing courses in acoustics in depth and formulate proposals for updated programs in the light of the new developments and needs.

HELINA must find ways to further promote the relation to industry and production related to acoustics. Special workshops can be organized for people working in industry and production covering basic acoustics as well as new, innovative applications, as a long- life education. The aim is to achieve a closer collaboration between HELINA and industry for the benefit of both parts.

It is obvious that finance is very important for the future and a key issue for all the described actions. The membership fees may be enough to maintain the operation of the Institute extra funding is needed, however, to support the future operation.

Closing this brief history of HELINA and of the acoustics in Greece, one can only be optimistic for its future development based on the dynamic new generation of Greek acousticians and its potential to deal with the challenges of the rising new era.

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FOUNDATION – DEVELOPMENT AND ACTIVITIES OF THE TURKISH ACOUSTICAL SOCIETY FROM PAST TO PRESENT

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ABSTRACT

Turkish Acoustical Society (TAKDER) was founded in 1992 under the leadership of academics from various departments of different universities such as architecture, electrical and mechanical engineering. In the following years, with the participation of experts interested in acoustics from different industrial branches, the Society has continued its existence until today by strengthening its infrastructure day by day, reaching large masses throughout the country, and increasing number of its members.

The Society has undertaken various tasks such as bringing “acoustics” to the forefront in different fields with national congresses held every two years, exhibitions and various events and publications embracing the society, raising awareness about noise in the society, and creating environments where academic studies are shared and discussed. Society also plays an active role in the field of education with the certificate programs carried out within the scope of the Regulations on acoustics in force in Türkiye.

TAKDER is a member of many international organizations operating in the field of acoustics, such as EAA, I-INCE, IIAV and ICA. The "Noise Control & Acoustics for Educational Buildings International Symposium" (2000) and the Inter-Noise 2007 Congress organized by the Society are important in terms of activities in the international arena.

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Keywords: Turkish Acoustical Society, activities in acoustics, certificate programmes, EAA, I-INCE.

1. INTRODUCTION

Turkish Acoustical Society (TAKDER) was established in 1992 in order to provide communication and cooperation between people working in various fields related to acoustics, conducting research and practice, informing the public about acoustics, to make them relevant and aware of the issue, in different universities such as architecture, electrical and mechanical engineering. It was established under the leadership of academics from various departments related to the subject.

The first establishment works as an acoustic association in Türkiye started in 1979 with the call of Ziyaeddin Süder (Prof.), Head of the Acoustic Study Group formed within the ITU (Istanbul Technical University) Faculty of Architecture, Building Research Institute, with the people coming together from different institutions and organizations. (at that time, YTU (Yıldız Technical University) faculty member Müjgan Şerefhanoglu (Assoc. Prof.) made efforts to establish the “**Society for Fighting Against Noise**” (GÜSAD), and it was at the stage of being established.) [1]

In the first meeting held in 1979, as a result of the negotiations, it was decided to start the studies for the establishment of the Acoustical Society, which aims to bring together the relevant people in the field of acoustics instead of GÜSAD, and it was decided that a commission consisting of Müjgan Şerefhanoglu (MŞS)



and Selma Kurra would work under the chairmanship of Ziyaeddin Süder. A small number of people, consisting of architects, electrical engineers and physics engineers, attended this first meeting. Although all kinds of legal preparations and initiatives were made in a certain period, the Acoustical Society could not be established in those years because the establishment of associations was stopped due to various reasons and especially due to the political environment of Türkiye at that time.

The efforts to establish associations, which required many bureaucratic procedures, came to the fore again in the following years, with the devoted efforts of Selma Kurra and Nurgün Tamer. 11 founding members, 10 of whom were university members, established the Society. The Acoustical Society held its first General Assembly meeting on 24.07.1992 and formed its board of directors. Since it is especially important in terms of international relations, the name of the association was changed to Turkish Acoustical Society (TAKDER) with the initiatives made in the period of 1994-1995.

Between 1992 and 2002, 184 individual members were registered to the Society. Considering the distribution of members by occupation, it is seen that mechanical engineers and architects constitute the majority. Apart from these, it is seen that medical doctors, electrical engineers, physics engineers, civil engineers and members from many other professions related to acoustics were registered to the Society during this period. (Tab. 1)

At the beginning of the 21st century, 32% of the members were women, while today this rate is 38%. In the following periods, the number of corporate members gradually increased and companies from different sectors operating in the field of acoustics joined the Society.

2. ACTIVITIES OF THE TURKISH ACOUSTICAL SOCIETY FROM PAST TO PRESENT

National congresses and exhibitions organized by the Turkish Acoustical Society (TAKDER) have played an important role in bringing together individuals and organizations operating in different fields of acoustics in Türkiye, from the establishment of the Society to the present. They take place every 2 years and are especially important in terms of bringing together people from different institutions who are interested in acoustics and/or working in this field. To date, national congresses have been held in various cities. The first national congress was the 1st National Noise Congress held in Bursa in 1994. Along with the congresses, exhibitions where objects such

as measuring instruments, acoustic instruments and ear protectors are introduced with the participation of various companies, also take an important place within the events.

Table 1. Distribution of Society Members by Occupation

Professions	Number of Members	pct. (%) Distribution
Mechn. Eng.	45	24
Architect	43	23
Dr.of medicine	18	10
Elec.Eltr. Eng.	18	10
Physics Eng.	14	8
Civil Eng.	13	7
Industrial Eng.	3	1.6
Chemical Eng.	2	1
Landscp. Arch.	2	1
Environ. Eng.	2	1
Sound Eng.	2	1
Musicologist	2	1
Opera artist	2	1
Geophys. Eng.	1	0.5
Psychologist	1	0.5
Student	6	3
Other	10	5

Apart from the national congresses, the Society organized an international symposium called "Noise Control & Acoustics for Educational Buildings International Symposium" (with collaboration of the YTU) in the year 2000, and afterwards in 2007 it hosted the Inter-Noise Congress in Istanbul. In addition, TAKDER has memberships at international organizations operating in the field of acoustics. These can be listed as; EAA (full membership (1995)), I-INCE (full membership (1997)), IIAV (membership (1997)), ICA (membership (2001)).

Although the issue of noise is actively included in the acoustic congresses, in the 5th Term work program of the Society, it has been decided to establish a unit called "**Fight Against Noise**" to be chaired by MŞS in line with the aim of increasing participation in the activities of the Society and similar purposes. Since noise is an important environmental issue and concerns the whole society, and since the role of individuals is important in reducing noise, it is aimed to raise awareness in the society, including children, on this issue, and therefore to

spread the awareness that some noises should not be emitted at all, some should be limited by laws and regulations, some can be solved with scientific and technical approaches, and when necessary, protection from noise is a right.

In order to raise awareness in Society on the fight against noise, the activities carried out by the “**Noise Fighting Unit**” within the scope of the **5th June World Environment Day** have an important place. Among the activities organized in this context; **seminars, symposiums and panels on "noise"** can be cited besides **competitions for posters, paintings, cartoons and composition** especially among high school and university students, within the framework of the programs determined every year. (Fig. 1)



Figure 1. First prize in the "noise" poster competition held among students.

The booklet titled "*Educational, Measurement and Laboratory Opportunities Related to Acoustics in Different Institutions in Türkiye*" prepared in 2000 is the first publication and original research of the Turkish Acoustical Society (TAKDER) and is an important document that provides information about the universities, institutions and laboratories operating in the field of acoustics in the country in these years. [2] Since the establishment of the Society, bulletins have been published by the board of directors in order to provide information to its members, and later the bulletins were developed further and the journal "*Acoustics*" was published including scientific and technical studies within its scope. However, this journal did not continue after the change of management in 2003 (Fig. 2).

The Turkish-English Glossary of Acoustic Terms has filled an important gap in this field, preparation studies of which were started a long time ago. It has been

published in 2022 as a result of reaching a consensus on certain issues. (Fig. 3 a, b)

The Regulation on the Evaluation and Management of Environmental Noise (ÇGDYY, 04.06.2010; 30.11.2022 revision) and *the Regulation on the Protection of Buildings against Noise* (BGKKHY, 31.05.2017), to which the Society (TAKDER) directly contributed were published by the Ministry of Environment and Urbanization in Türkiye.

[3,4] In the ÇGDYY, environmental noise sources are identified and limit values that should not be exceeded for urban areas with different sensitivity levels are given. The ÇGDYY has enabled the creation of noise maps, which are important both in terms of settlement planning and in terms of taking measures against noise at the building envelope of buildings, and initiated studies on the preparation of comprehensive action plans for the future.

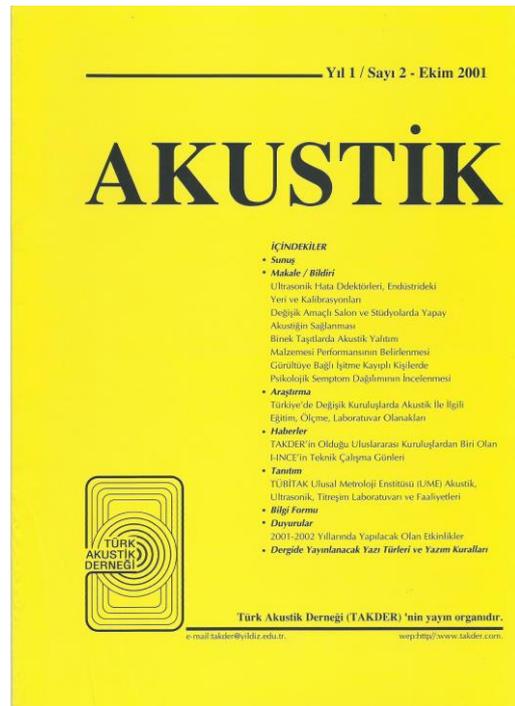


Figure 2. Cover of the Acoustic Journal.

In BGKKHY, it is stated that the acoustic performance certificate should be issued by a building acoustics specialist for the whole building. For this reason, it has become necessary to train acoustics experts who would fulfil these duties. For this purpose, the Ministry has asked universities and organizations that can provide certificate trainings for acoustics experts.

The Society (TAKDER) is one of these organizations who provides Basic Building Acoustics Certificate Program (D1) and Building Acoustics Measurements Certificate Program (D2). These training programs, as well as other financial activities, are organized by an Economic Enterprise (2018) operating under the Society in order to be carried out more effectively and in accordance with the law.



Figure 3. a) Turkish-English Glossary of Acoustic Terms.

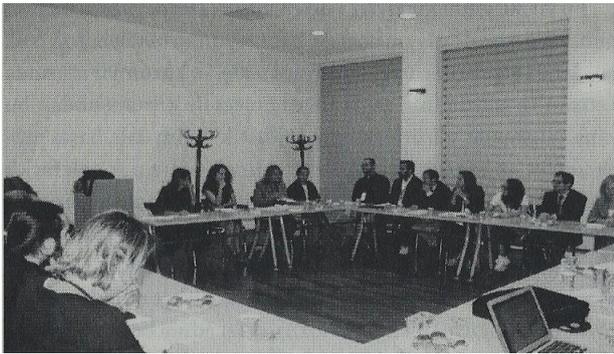


Figure 3. b) Meeting on preparatory studies of the Turkish - English Glossary of Acoustic Terms.

3. SOCIAL ACTIVITIES OF THE TURKISH ACOUSTICAL SOCIETY

The Society (TAKDER) is a non-governmental organization that is constantly on the agenda with the scientific congresses and exhibitions it organizes, as well as with the social activities it organizes to raise public awareness and disseminate scientific knowledge about acoustics. [5,6] Some of the important ones among the **seminars, symposiums** and **conferences** organized by the Society can be summarized as follows:

Acoustic Problems and Noise Control in Environment, Construction and Industry, Seminar, 1994 (a conference on *Noise Effects* was also given by Prof. C. Rice.).

Hearing Mechanism of the Ear, Conference, 1995 (Prof. Dr. İrfan Devranoğlu).

Acoustic Problems in Buildings and Solutions, Seminar, 1996.

Applied Modal Testing. Theory and Practice, Seminar, 1996 (Prof. David J. Ewins, Harry Zaweri).

Sound Quality, ITU-EAA Tutorium Seminar, 1997 (Prof. Blauert).

Fight Against Noise, Symposium and Panel, 1997.

Environment - Noise - Human, Panel, 1999.

Acoustics in Music Rooms, Conference, 1999 (Prof. Şazi Sirel).

Fight Against Noise, Conference, 2021 (Prof. Müjgan Şerefhanoglu).

International Noise Awareness Day Symposium, 2022.

Noise Barriers Calculation and Design Seminar., 2022.

Basic Acoustics Seminar: Noise and Vibration Control, 2022.

Regulation and Guide for the Protection of Buildings from Noise: Guide for Protection from Noise by Design Seminar, 2019.

Architectural Acoustic Report Preparation Principles, Seminar, 2018.

In addition to all these activities, the informative publication titled “*Explanations on the Implementation of BGKKHY*” (2019), “*Legislation and Practices for Sound Insulation in Buildings Training*” (2021), D1 and D2 certificate trainings (within the scope of BGKKHY) can be cited among the Society's activities in the field of education. In addition, technical trips carried out in different periods are also important both in terms of education and relations with different organizations such as; Acoustical Laboratories in the National Metrology Institute of the Scientific and Technological Research Council of Türkiye (UMETÜBİTAK), Arçelik Inc. Co. Acoustic and Vibration Laboratory (1995), TEE Inc. Co. Vibration and Acoustic Laboratories (1996). (Fig. 4)

The competitions organized to raise awareness about "noise" in society are also important in terms of the Society's social activities. These competitions have been evaluated by the selection committees where prominent artists and writers were jury members.

In addition to all these activities in various fields, certain commissions have been established to work in different fields of acoustics, which are expected to operate in areas such as standards and regulations, acoustic terms, building and environmental acoustics, machinery noise and vibrations, etc. since the foundation of the Society.



Figure 4. Technical trip to the Acoustical Laboratories in the National Metrology Institute (UME – TÜBİTAK) with the participation of the board members of TAKDER and graduate students.

Among these competitions can be cited as follows; Poster Competition on "noise" among students of architecture and fine arts faculties of universities (1997), Painting Competition on "noise" organized among high school students within the scope of the **"Fight Against Noise"** program (2001), Composition Competition on **"Noise and Its Effects"** organized among high school and university students, **"Sounds in My World"** competition organized among primary and secondary school students within the scope of the **International Year of Sound (2021)**.

The Cartoon Contest on "Urban Noise", which was open to all participants, especially to professional cartoon artists, within the scope of the 10th anniversary activities of the Society and the **World Environment Day - Fight Against Noise** program, is of particular importance among the social activities organized by the Society (2002). Among these activities, the Cartoon Contest had a special place, and the posters selected as a result of the competition were exhibited in the show windows of the famous stores in two important regions of Istanbul. Exhibitions were also organized at 4 different galleries in different cities outside Istanbul. In addition, a cartoon exhibition book on "Urban Noise" was printed from the selected posters (Fig. 5 a, b).



Figure 5. a) Winner of the Urban Noise Cartoon Contest.



Fig 5. b) Cartoon exhibition book on Urban Noise.

Competitions and social events organized in cooperation with various individuals and organizations have enabled the Society to play an active role as a non-governmental organization in the social arena. It has become a tradition to organize events such as dinners, cocktails, music concerts, etc. every year to bring together the members and their relatives in the Society, to get acquainted, to exchange information with the management, and to have a good time. In addition to the social benefits provided by these social events, they have also contributed to the income of the Society, albeit to a lesser extent.

4. FUTURE VISION OF THE TURKISH ACOUSTICAL SOCIETY

Turkish Acoustical Society (TAKDER) aims to continue its activities both nationally and internationally in the future. In the national arena, it aims to further increase the number of individual and corporate members and to spread throughout the country, in order to organize competitions and various activities on special days, to increase the number and quality of national congresses organized, and to carry out educational activities more intensively.

In the international arena, the Society has the objective to carry out closer cooperation with international institutions such as EAA, I-INCE, IIAV, ICA to establish joint working groups and organizations with universities and other associations active in this field, to determine common working areas and to support the creation of the necessary infrastructure for joint tasks on issues of importance for the benefit of society, as well as the realization of joint research projects. Especially organizing international congresses and exhibitions in Türkiye in the field of acoustics, after the Inter-Noise 2007 Congress in İstanbul, in cooperation with these international institutions will contribute to the effective cooperation of the universities and companies in the sector internationally.

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GERMAN STANDARD DIN 4109 (SOUND INSULATION IN BUILDINGS) IN THE CONTEXT OF TECHNICAL, SCIENTIFIC AND SOCIAL DEVELOPMENTS

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ABSTRACT

For many years, the standard DIN 4109, which regulates sound insulation in buildings at a legally obligated level, has been the relevant standard for building acoustics in Germany. It not only specifies the requirements for sound insulation, but also regulates measurement procedures and calculative verifications. The origins of this standard date back to 1938. Since then, the content and form of this standard have constantly evolved. This standard has always been the subject of lively discussions. This contribution emphasises at the progress of this standard in view of the many technical, scientific and social developments from its origins to its current status. It can be shown that requirements on the one hand and acoustical verifications on the other have developed in different ways. At the same time, the history of DIN 4109 also shows the development of building acoustics in practical application.

Keywords: *standard, sound insulation, regulation, building acoustic*

1. INTRODUCTION

The German standard DIN 4109 (Sound insulation in buildings) is virtually an institution in Germany that plays a prominent role in building acoustics. It has a long history in which, on the one hand, it has always significantly influenced the development of building acoustics in Germany and, on the other hand, it has taken up developments from building acoustics practice and research. In this respect, it seems justified to give this

standard the appropriate attention in the present historical context.

2. DIN 4109 AS THE CENTRAL SET OF RULES FOR BUILDING ACOUSTICS

DIN 4109 is the authoritative standard for building acoustics in Germany. From the very beginning, it has taken on the task of formulating the requirements for building sound insulation set by the state in the course of the building regulations. This is often seen as its most important task. As a standard, DIN 4109 is created in a regular standardisation process (in accordance with the statutes for standardisation work in DIN 820) at the German Institute for Standardisation (DIN), but it only attains the status of a legally binding specification through the subsequent "introduction by the building authorities". A special feature of DIN 4109 is that it not only specifies the requirements of building sound insulation, but also contains specifications on how compliance with them can be verified and gives advice on how they can be realised. In Germany, the verification of compliance with the requirements of DIN 4109 is usually carried out by calculation, but metrological verification is also regulated. In addition, DIN 4109 contains instructions for planning and implementation right from the start. Thus, DIN 4109 in its entirety is above all a comprehensive planning instrument that covers all areas of the design of structural sound insulation. It thus has a far-reaching effect on building practice.

This comprehensive claim actually makes DIN 4109 an institution of building acoustics of far-reaching importance in Germany. This central role within the framework of building acoustics standardisation is reinforced by the fact that it is closely linked to the building acoustics test procedures for laboratories and buildings via the verifications. These have been required since 1962 in DIN 4109 in order to be able to carry out the suitability and quality tests mentioned there. Thus, the measurement and assessment procedures defined at the German level,

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together with DIN 4109, formed a common and complete German standard concept of sound insulation in buildings. This was only dissolved when the building acoustics measurement procedures for Germany were also gradually internationalised by ISO and EN standards and the German measurement standards had to be (largely) withdrawn. Since the 1962 version, DIN 4109 also provided for suitability and quality tests. It was stated: "Suitability tests are to be carried out by an officially recognised testing institute". Under the supervision of the then IfBt (Institut für Bautechnik, today DIBt), a separate verification system with Group I testing bodies approved for this purpose was created. For a long time, these bodies were heavily involved in the further development of DIN 4109 and in research projects related to DIN 4109. In addition, there were also the quality testing bodies to carry out the quality tests mentioned in DIN 4109 Blatt 2:1962 in the building inspection procedure. This inspection system of the quality inspection bodies still exists today. Separate qualification guidelines and quality assurance systems were established for the test centres, in which the IfBt and the Physikalisch Technische Bundesanstalt (PTB) were involved. All in all, it can be seen that a comprehensive set of standards and verification systems was created for sound insulation in buildings, the centrepiece of which was DIN 4109. Only in this context the importance of DIN 4109 for building acoustics in Germany can be recognised.

3. HISTORY OF DIN 4109

When DIN 4110 (Technical Regulations for the Approval of New Construction Methods, 2nd edition, Berlin July 1938) was published in 1938, it was the first German standard to deal with sound insulation in buildings and to make specifications for airborne and impact sound transmission. What started with a volume of about one page ended (for the time being) with DIN 4109:2016/2018 on more than 400 pages, distributed over ten individual parts of the standard. This quantitative consideration alone gives an idea that the normatively regulated sound insulation in buildings was subject to constant development and expansion of its scope of application. From the first specifications on sound insulation to the current status - then under the name DIN 4109 - a body of standards has developed that not only specifies the requirements, but also deals with metrological and computational verifications, specifies building element data ("implementation examples") and provides information for planning and implementation. Thus, this standard has gradually developed from ensuring the protection requirement from

the state's point of view to the central set of rules for sound insulation in buildings, which not only provides the requirements and verification concept for the state-regulated area, but also represents a modern and efficient tool for building acoustics planning.

A short overview shows some important steps of the development:

- DIN 4110:1938 formed the beginning of normative regulations for sound insulation as "Technische Bestimmungen für die Zulassung neuer Bauweisen".

- DIN 4109:1944 (Richtlinie für den Schallschutz im Hochbau) was the first separate standard for sound insulation in buildings and established the tradition of this standard under the name DIN 4109, which was used for the first time.

- DIN 4109:1962 (Schallschutz im Hochbau) led to the first major revision of DIN 4109 with a total of 5 sheets and was introduced by the building authorities.

- DIN 4109:1989, together with Supplements 1 and 2, was given a new structure and for the first time contained computational verifications for heavy and lightweight / timber construction. For this purpose, the required component data were supplied in the form of "design examples".

- With DIN 4109:2016, DIN 4109 was adapted to the European standards of sound insulation in buildings and underwent a complete redesign.

It can be seen that every 25 years or so (1938/1962/1989/2016) significant steps were taken to further develop the standard. In the current version, DIN 4109 has five standard parts: DIN 4109-1 with the minimum requirements, DIN 4109-2 with the calculation methods, DIN 4109- 31 to 36 with the building element catalogue, DIN 4109-4 with the building acoustic tests and DIN 410-5 with the increased requirements.

The building element catalogue forms the data basis for the computational verifications in DIN 4109-2. In view of new data not previously required (e.g. for direct sound reduction or vibration reduction index) and the updating of data (especially for timber and lightweight construction), the new building element catalogue reached such a volume that a thematic division into 6 parts was made. It is intended that the building components catalogue will be continuously developed. Further developments are also planned for the calculation methods in DIN 4109-2 in the ongoing revision. Thus, although DIN 4109 has a long history, it has not yet reached the end of its development - at least with regard to the calculation methods and the component catalogue. In its current state, it provides a consistent set of rules for requirements, verification, planning and execution of sound insulation and is thus the only set of rules in Germany that

completely covers this area. In addition to its significance under public law, it is also a contemporary instrument for the entire building acoustics planning and design that meets current expectations.

4. DIN 4109 IN THE CONTEXT OF SCIENTIFIC DEVELOPMENTS IN BUILDING ACOUSTICS

There is no doubt that DIN 4109 is involved in the scientific developments in building acoustics. On the one hand, it tried very early on to use the scientific input of the field for itself and to take up scientific results. For example, when the edition of the standard was introduced in 1962, the following comment was made: "The standard DIN 4109 is thus a typical example of the evaluation of scientific investigations for the direct work of building practice." On the other hand, DIN 4109 has also repeatedly provided impetus for building acoustics research and thus ensured further development of building acoustics. Among the people who have made a decisive contribution to the scientific development of building acoustics in recent times, Lothar Cremer and Karl Gösele are particularly worthy of mention. Their contributions will be highlighted by means of a few exemplary examples. In addition, it should not be forgotten that significant contributions were also made outside the scope of DIN 4109 and were taken note of in the context of DIN 4109. These include, for example, the work from the Bauakademie of the GDR around W. Fasold, the Reichardt'sche Schule with the Institute for Electrical and Building Acoustics at the TU Dresden and the work of J. Lang (Vienna).

Lothar Cremer was extremely active in the field of acoustic standardisation. In particular, he contributed to the national and international standardisation of building acoustics. Some of his most important contributions, which are directly related to the acoustic issues of DIN 4109, are mentioned here as examples.

In [1] Cremer deals with the theory of sound insulation of thin walls at oblique incidence. Together with M. Heckl, "computational and experimental investigations of sound bridges in double walls" are then also carried out [2]. Cremer also made essential contributions to impact sound. Especially known is the "Theory of Impact Sound" published in 1948 [3]. In the 1950s, when floating screeds became more important as a building acoustic solution, a comprehensive understanding of this construction method was needed and Cremer contributed a fundamental theory [4].

An important issue for building acoustics was the formation of single-number values for sound insulation on the basis of

reference curves. Cremer made significant contributions to this [5]. Questions of sound insulation that are of importance in practical application and are relevant to DIN 4109 have also been reflected in Cremer's and Heckl's basic work on structure-borne sound [6]. There, for example, the generation of impact sound and the excitation by the standard tapping machine are dealt with. Continuous coupling through elastic intermediate layers, as occurs with floating screeds, or double walls with sound bridges are also discussed.

Karl Gösele's name is associated with building acoustics and DIN 4109 like hardly anyone else. Gösele himself was "an institution" in building acoustics standardisation. A basic constant of his work is that it was always oriented towards practical problems and claimed to be implemented in practice. Thus, one can justifiably claim that Gösele as an individual has influenced the development of DIN 4109 like hardly anyone else. The range of his activities can be illustrated with a few examples.

In 1968, he dealt with the airborne sound insulation of single layerd walls and ceilings in [7]. The investigations led to the derivation of a "mass curve", as it was later found in DIN 4109. A paper on the reduction of airborne sound insulation of walls by thickness resonances can be found in [8]. Again and again, it was doublewall building components that attracted his attention due to practical problems [9], [10], [11] and [12]. Gösele has also worked intensively on impact sound. Fundamental works include [13], [14] and [15]. He dealt also with the calculation of impact sound insulation of wooden beam ceilings in [16].

Like Cremer, Gösele also dealt with the formation of single-number values for sound insulation [17]. Of great influence on DIN 4109 was his work on flanking sound transmission, which not only deepened the understanding of the relevant processes, but was also the basis for new prediction methods for airborne sound insulation in buildings. As early as 1968, the "Untersuchungen zur Schall-Längsleitung in Bauten" [18] were published, in which - long before later in the EN 12354 and then also in the DIN 4109-2:2016 the vibration reduction at junctions appeared - these quantities were already examined in detail and made determinable with computational approaches. The method presented in 1984 for the calculation of airborne sound insulation in buildings considering flanking sound transmission [19,] was groundbreaking. It corresponded in its essential features to the method that was later also used in EN 12354-1 and DIN 4109-2:2016. As flanking walls became lighter and lighter in the course of changing construction methods, Gösele also dealt with this increasingly evident problem [20]. In numerous publications, Gösele, often together with C. A. Voigtberger, has also taken up the then very acute valve

and tap noises. At this point, reference should be made to [21] as an example of such work.

In addition to individuals, institutions involved in research should also be mentioned. These are mainly those institutions that belonged to the officially designated Group I test centres for proficiency testing, e.g.: Institute for Technical Physics Stuttgart (later Fraunhofer Institute for Building Physics) with K. Gösele, Institute for Technical Acoustics of the TU-Berlin with L. Cremer, Federal Institute for Materials Research and Testing (BAM) in Berlin with P. Schneider, Materialprüfungsamt NRW Dortmund with A. Eisenberg, Materialprüfanstalt für das Bauwesen Braunschweig (MPA Braunschweig) and Physikalisch-Technische Bundesanstalt Braunschweig (PTB). Time and again, significant contributions came from these institutions, which were reflected in DIN 4109.

The Federal Ministry of Construction and the German Institute for Building Technology (DIBT), which has operated under different names over the past decades, are the institutions that promote research in the field of building acoustics. Numerous research projects directly related to the issues of DIN 4109 were funded by these government agencies. The "Berichte aus der Bauforschung" (Reports on Building Research), which were published between 1956 and 1975 and document 20 years of state-funded application-related building research, are now historical records of the building acoustics research projects funded by the Federal Ministry. A total of 7 anthologies on building acoustics are listed, edited by L. Cremer, A. Eisenberg and M. Heckl. They demonstrate the variety of building acoustics issues that were dealt with in these research projects. It is easy to recognise the direct relationship of the topics to the issues of DIN 4109. Research received a new impulse with the European standardisation of sound insulation in buildings, which shook up some of the fundamentals of DIN 4109 and led to a hitherto unknown scope of research projects preparing and accompanying standards. The impending changes, especially due to the building acoustics measurement methods and the EN 12354 prediction methods, created a great deal of pressure on DIN 4109. It was significant that not only the public sponsors (Federal Ministry of Construction and DIBT), but above all the building materials industry and the construction industry (especially in the area of solid construction) participated in the projects to a very considerable extent.

Even today, European standardisation is still an important stimulus for building acoustics research in Germany. An outstanding example at the moment is building services equipment. Although DIN 4109 specifies sound insulation

requirements for this area, it does not yet contain any computational verification methods.

Thus, since the mid-90s of the last century, building acoustics research has experienced an unprecedented intensification in the context of European standardisation and DIN 4109, which has made it possible to place the calculation and verification procedures of DIN 4109 on a completely new footing and to provide building acoustics planning with a modern and efficient instrument. Since the requirements for sound insulation are not affected by the European regulations and there was no will in the standards committee for DIN 4109 to carry out a modernisation here (e.g. a change of single number quantities for the requirements), the area of requirements has not benefited from this impulse.

5. DIN 4109 IN THE CONTEXT OF TECHNICAL DEVELOPMENTS IN BUILDING ACOUSTICS

Since DIN 4109, by definition, sees its scope of application in building acoustics practice, the reciprocal relationships between DIN 4109 and technical developments in building acoustics are particularly pronounced. In reality, a separation between the scientific developments discussed in the previous section and the technical developments is not clearly possible. There are always overlaps here.

DIN 4109 is constantly under obligation to reflect current construction methods and thus follow technical progress. However, in view of the long time intervals between the individual editions of the standard, it has only succeeded in doing so with great delays. However, the new structure of DIN 4109 from 2016 and the restructuring of the standardisation work on DIN 4109 since 2006 have changed this. The calculation methods, just like the building element catalogue, are now set out in separate parts of the standard, so that they can be supplemented and updated independently of other parts of the standard. This has already happened several times since the 2016 versions were published. In the opposite direction, however, DIN 4109 has also repeatedly supported, initiated or even forced technical developments in building acoustics. Examples are floating screeds, double-shell house partition walls, developments in flanking transmission in solid and timber construction, as well as developments in fittings and equipment for water installations. Some of these developments are discussed below others for example the metrological verifications or the development of an installation test stand have to be omitted.

5.1 Homogeneous building elements and flanking transmission

When in 1989, for the first time, computational verifications for sound insulation in buildings were introduced in DIN 4109, the verification for buildings in solid construction was based on two simplifications: the sound insulation of a (homogeneous) partitioning element was determined from its mass per unit area and a mean flanking sound transmission was already taken into account in the computed value $R'_{w,R}$. This $R'_{w,R}$ was a value for the sound insulation determined by measurement in a test stand with flanking transmission similar to that of the building in accordance with DIN 52210, which already contained an "average" flanking transmission. If necessary, this had to be corrected by correction factors ($K_{L,1}$ and $K_{L,2}$) if the conditions of the building differed from those of the test stand. For practical use, this was an extremely simple matter, which also led to reasonable results for homogeneous construction common at the time. However, later on, when construction had developed further, it also led to limitations, because not all constructive variants were sufficiently considered. The limitations of this method became particularly apparent in the case of light flanking walls and highly insulating perforated bricks in the outer wall. In these cases, planning errors occurred again and again due to the assumptions of the verification method no longer being fulfilled. In contrast, DIN 4109 has been progressive since 1989 in the treatment of buildings in timber and lightweight construction. The prediction procedure provided for there corresponded in essential approaches to today's procedure of EN 12354-1 on the basis of a complete model.

Based on investigations such as those presented by Gösele in [22], it was realised that thermal-insulating perforated bricks could not be considered as homogeneous building components due to their perforated structure, whose sound insulation value can be determined from the mass per unit area. Extensive investigations led to a fundamental understanding of the phenomena that occur and to constructional solutions in the form of acoustically optimised perforated bricks. But it was also possible to put the acoustic prediction for such constructions on a new footing, based on the procedures of EN 12354. DIN 4109 was thus the first set of acoustic regulations that made it possible to take such products into account in planning and to provide acoustic proof.

The old method had reached its limits of validity for the flanking transmission of light solid walls. The detailed consideration of the flanking sound transmission in accordance with the calculation methods according to EN 12354 made it clear that the component connections

(joints) with the new K_{ij} parameter must also be considered and taken into account. In the run-up to the new DIN 4109, the implementation of the European calculation methods led to numerous research and development projects dealing with the acoustic behaviour of joints and the flanking transmission. This resulted in optimised joint solutions, e.g. for exterior walls in brick construction or for the decoupling of lightweight solid walls. Such constructive solutions have found their way into building practice and have also been partially anchored in DIN 4109 (calculation method and component catalogue) since 2016.

5.2 Floating screed

In building practice, it was clear very early that impact sound insulation could be achieved most easily with a floating screed and that high values of impact sound insulation could only be achieved with this. As with the double partition walls before, this construction method also proved to be extremely prone to errors due to the danger of sound bridges. Initially, it was not possible to calculate the expected impact sound insulation, but as early as 1952, in the draft of DIN 4109 Supplement, March 1952, DIN 4109 felt compelled to provide information on the correct building design and installation.

DIN 4109:1962-09 even published a part of the standard, Sheet 4 (Floating screeds on solid floors, guidelines for execution), which dealt exclusively with floating screeds and issued guidelines for their construction. DIN 4109 thus ensured that the floating screed could become a reliable standard construction. It was not until DIN 4109:1989 that a mathematical verification procedure could be implemented in DIN 4109. This contributed to the spread of floating screeds and their further technical development.

5.3 Noise of water installation

An outstanding example of the influence of DIN 4109 on the technical development of products as well as the development of suitable measurement methods is the noise of taps and devices in water installations. The starting point was that there were quite considerable problems with the noise of fittings in the 50s and 60s of the last century. The lack of suitable low-noise products corresponded with the lack of a suitable method for assessing noise generation. The only solution was quite rightly seen in the need to create a suitable test procedure for valve noise. Due to extensive research (P. Schneider and K. Gösele), an appropriate measurement procedure was developed, which was then published as a draft standard in November 1968 and finally in 1972 as the standard DIN 52218 (Testing of

the noise behaviour of appliances and water installation devices in the laboratory).

The DIN 52218 measurement procedure initiated by DIN 4109 can be considered extremely successful. Within a short period of time after the introduction of the new measurement procedure, the massive complaints decreased drastically and nowadays the actual fittings usually only play a subordinate role in sound insulation in practice. The measurement method of DIN 52128 was then adopted into international standardisation in 1977 as ISO 3822-1, where it is still the internationally applicable measurement method within the framework of the ISO 3822 series.

6. DEVELOPMENT OF THE VERIFICATION PROCEDURES IN DIN 4109

At first, there was no calculation at all in DIN 4109. It worked with descriptions of components and constructions with which compliance with the requirements could be expected. This did not change in DIN 4109:1962 either. In its Sheet 3 (Design Examples), however, the construction details explicitly named "Design Examples" for the first time were given a significantly larger scope.

With DIN 4109:1989 and its Supplement 1 (Design Examples and Calculation Methods), the verifications were carried out mathematically for the first time. New were the calculation procedures for sound insulation in skeleton structures and timber buildings and in solid construction. Since then, the usual verification in Germany has been the calculation. In the 1989 standard, care was taken to ensure that the calculation procedure was as simple as possible so that it could be mastered by the "verifiers", most of whom were architects or civil engineers. Logarithmic calculations were avoided as far as possible. Instead, tables, diagrams and correction values were used. In Supplement 1 to DIN 4109, in view of the newly included computational verifications, design examples with acoustic characteristic values were now also included. The component data now served as input data for the calculation procedures, which was a new approach in the history of DIN 4109. These verifications were simple and practicable for the standard situations of building in Germany at that time. However, these procedures could not keep up with the development of building technology, so that reliable verification was no longer possible for certain applications (e.g. for exterior walls made of thermal insulating perforated bricks or for lightweight homogeneous flanking components). These gaps could be closed with DIN 4109:2016, when the European prediction procedures of EN 12354 were implemented in DIN 4109. At the same time, this step led to

the fact that more extensive calculation procedures now also had to be applied according to DIN 4109-2, for which, however, suitable calculation programs are available.

From "logarithm-free" verification to software-supported detailed calculation, DIN 4109 has thus undergone a major development and is thus at the technical level expected today.

7. DIN 4109 IN THE CONTEXT OF SOCIAL DEVELOPMENTS

A standard dealing with sound insulation in buildings is inevitably the focus of different social interests. This has been shown time and again in the history of DIN 4109. The protection of occupants and building users should be in the foreground. They expect contemporary sound insulation that is adapted to today's needs and to technical developments. The technical conditions must be taken into account in the realisation of sound insulation. In particular, the economic efficiency of building is a dominating force in the discussion about the specification of sound insulation requirements. Specific issues of jurisdiction have also played a significant role again and again in the history of DIN 4109. The legal certainty of the specified requirements (e.g. in the sense of generally recognised rules of technology) was repeatedly addressed. As a DIN standard, DIN 4109 is processed in the Building Standards Committee (NABau). The standardisation work is bound to the standardisation principles of DIN 820, according to which the "interested parties", i.e. not only acoustic experts, are to be involved in the standardisation process. In the standards committee for DIN 4109-1, the interested parties include building material manufacturers, building contractors, the scientific community, the housing industry, building inspectors, consulting engineers, architects and housing users.

Given the very different interests of these groups, it is no wonder that the standardisation work on DIN 4109 in the area of requirements has been controversial and tough again and again in recent decades. It is therefore not surprising that the time intervals between the respective new editions were long: 1944 - 1962 - 1989 - 2016.

In view of the long periods of time between the individual editions of DIN 4109, it is surprising that the requirements have hardly changed in essential points since 1938. When DIN 4110 appeared in 1938 as the predecessor of DIN 4109, it was about the provision of living space on a large scale. For flat partition walls, a mass per unit area of at least 450 kg/m² was required, which meant that a weighted sound reduction index R_w of about 54 to 56 dB could be

achieved with the construction conditions common at the time. For the partition wall, whose sound insulation is decisive for the sound insulation of a flat, virtually nothing has changed, as in DIN 4109 of 1989 and the latest version DIN 4109-1 of 2018, an R'_w of 53 dB is required for the minimum requirements. When drafting this currently valid version, it was explicitly stipulated in the standards committee for the requirements that "no significant changes to the level of requirements" should be made. This explains why, despite high public expectations, the sound insulation level of DIN 4109:2016 was not adapted to today's ideas of contemporary sound insulation to the desired extent 27 years after DIN 4109:1989 was published. Whereas DIN 4109 used to be one of the leading requirements in Europe in terms of sound insulation, it has long since lost this status. Due to developments in numerous other countries, DIN 4109 has lagged behind in this respect.

The conflict between the residents' expectations of sound insulation and the demand for economic efficiency from the building and real estate industry is as old as the specification of sound insulation requirements and runs through the entire development of DIN 4109. Time and again it could be seen that in the end economic interests were given priority. An example of this is the draft standard DIN 4109 from 1979.

There, after a long time, a contemporary adjustment of the sound insulation level had been planned. This was withdrawn again in the 1984 draft standard. In the remarkable explanations of the chairman on the changes made in principle, the following was mentioned in the draft for Part 2: *"... the abandonment of the planned increase in the requirements for airborne sound insulation of partition walls and ceilings in dwellings compared to DIN 4109, 1962 edition, due to the comments received on this draft standard, which were directed in particular against the increases in construction costs associated with the increases in the requirements"*.

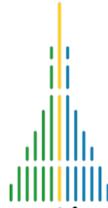
As a conclusion, it can be stated that DIN 4109 is not an impulse generator in terms of requirements. It does not follow social developments and does not consistently take up developments in building technology. In the described field of conflict, it cannot be expected that the requirements of DIN 4109 per se reflect contemporary sound insulation. One must rather attest them a retarding status. Requirements in other countries (e.g. Switzerland, Austria) are now much more advanced. As a result of the existing dissatisfaction with the requirements of DIN 4109, further sets of rules on the requirements in sound insulation in buildings have therefore emerged in Germany, e.g. in 1994 the VDI 4100 (Sound insulation of dwellings; criteria for planning and assessment], in 2009 the DEGA sound

insulation certificate (DEGA Empfehlung 103, Schallschutz im Wohnungsbau–Schallschutzausweis), in 2015 the DEGA Memorandum BR 0104 on sound insulation in one's own living area (Schallschutz im eigenen Wohnbereich) and in 2020 the DIN 4109-5 (Erhöhte Anforderungen). All of the above-mentioned regulations are not relevant for building inspectorates.

Further potential for conflict is provided by the existing law in Germany, which distinguishes between state requirements in the sense of requirements under public law and the properties of a building owed under contract and private law, whereby the so-called generally recognised rules of technology are of particular importance. Both areas are not necessarily identical in the derivable requirements. Therefore, conflict situations arose again and again in the historical development of DIN 4109. These led several times to "adjustments" because the discrepancy between the minimum sound insulation according to DIN 4109 and a sound insulation corresponding to the generally recognised rules of technology had become too great. This was the case, for example, with the requirements for impact sound, which could be significantly increased in the 1989 edition due to the floating screeds that have become standard in the meantime. A comparable situation occurred in 2016 for the sound insulation of house partition walls, for which the minimum requirements were also raised compared to the 1989 edition due to double-wall construction that has become the norm.

8. SUMMARY AND OUTLOOK

DIN 4109 represents the central set of regulations for building acoustics in Germany. It is integrated into a comprehensive standardisation concept of sound insulation in buildings and forms its core. It formulates the minimum requirements to be met by the state and regulates the verification of compliance. In addition, however, in its historical development it has become a comprehensive planning instrument for building acoustics, which represents the most current status, especially through the implementation of the European calculation methods of EN 12354. In view of its importance, it is subject to manifold influences, but on the other hand it also exerts great influence. These mutual relationships are discussed in this article under the aspects of historical, scientific, technical and social developments. From this it can be seen what an outstanding role DIN 4109 has played for a long time in building acoustics in Germany. It can be considered an "institution" of building acoustics for good reason and well known acousticians like Cremer, Heckl or Gösele



promote the building acoustic standardisation in DIN 4109. When assessing the development of the content of this standard, a divided picture emerges: the computational procedures for the verification of the required sound insulation in conjunction with an efficient building element catalogue have constantly developed further by gradually taking up and implementing the scientific and technical advances in building acoustics. They are thus up to date and are constantly being further developed. The situation is different with the requirements. The formulation of requirements has stagnated for decades. Adaptations to social developments have hardly taken place. Moderate changes in the level of requirements have only been made in some areas, and only when forced by external requirements (e.g. jurisdiction). In view of the controversial interests in the level of noise protection, no significant changes are to be expected.

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THE HISTORY OF THE EUROPEAN ACOUSTICAL JOURNALS SINCE 1930: AN OVERVIEW

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ABSTRACT

The first acoustics journals were published in the 1930s. Some European Societies launched specialized journals, and at the same time, the *Journal of the Acoustical Society of America (JASA)* started its publication in 1929. The growth of *JASA* was regular and significant, while the European journals slowed down due to the Second World War. Publication in various languages was an added difficulty for European journals. A consequence was a significant contribution of European scientists to the growth of *JASA*: success breeds success. This is illustrated by various figures found in bibliographic databases. Then started the long road leading from 1951 to the European Acoustic Association (EAA) and its present journal *Acta Acustica (AA)* in open access. Some national societies decided to continue their journal, while others decided to stop. Recently the EAA launched a large portal, named Documenta Acustica Electronica (DAEL), to collect the archives of all European journals, conferences, reports, PhD theses, etc.

Keywords: *Acoustics journal, European journal, Acta Acustica.*

1. INTRODUCTION

During the 19th century, acoustics research was reported in broad scope scientific journals. Well-known examples

are *Philosophical Magazine*, *Poggendorff Annalen*, *Compte rendus de l'Académie des Sciences* etc. Peer reviewed journals specialized in acoustics appeared after the First World War. The first one is probably the *Journal of the Acoustical Society of America* (I, 1929-). Then the Sound Foundation Geluidstichting published a journal in the Netherlands (1934-1960). At the same time, Presses Universitaires de France published the *Revue d'Acoustique* (1932-1940) and the German Science Foundation the *Akustische Zeitschrift* (1936-1944).

The aim of the present paper is to compare the journal of the European Acoustical Association to the Journal of the Acoustical Society of America. For this purpose, we used Web of Science (Clarivate) data on the number of articles published in the respective journals. (NB: conference proceedings are not considered).

2. ACUSTICA

After the Second World War, in 1951, the decision was made to publish the first European acoustics journal. This date is also that of the European Coal and Steel Community treaty! The name was *ACUSTICA*, the Publisher was Hirzel Verlag, and articles were published in English, French and German. A majority of articles was published by German scientists. The abstracts were published in three languages. The journal covered all topics in acoustics. Supplements were also published as

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Akustische Beihefte (1951-1963). The multiple countries and languages implied difficulties for the creation of *Acustica*, in addition to the sequels of the Second World War. This explains the large difference between *ACUSTICA* and *JASA*, which had increasing success.

30 years after its birth, the number of articles published in *ACUSTICA* remained much lower than the number in *JASA* (see Fig.1). Furthermore, the European journal remained essentially European, while the American journal remained mainly American. The numbers correspond to the affiliation of at least one author, according to Web of Science [This results in an overestimation of about 10% as some articles have multiple authors with affiliations in different countries.].

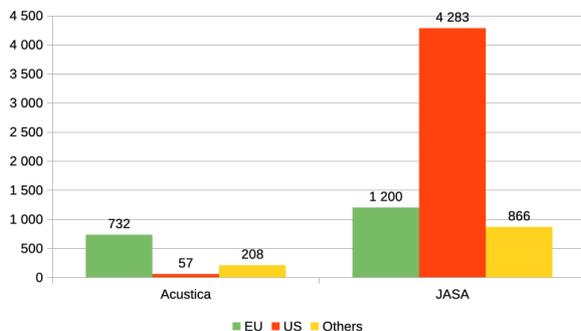


Figure 1. Number of articles during the period 1980-1992 in *ACUSTICA* and *JASA* (Source: Web of Science).

3. THE EUROPEAN ACOUSTIC ASSOCIATION

In 1992, the European Acoustics Association (EAA) was created as a non-profit entity. Today 33 National Societies are EAA members, with a total of 9000 individual members. The EAA decided to create a journal, under the name *Acta Acustica* (1993-1995), the publisher being Les Editions de Physique (now EDP Sciences). It benefited from the cessation of the *Journal d'Acoustique* (1988-1992) decided by the French Acoustical society (SFA). Later the Italian Acoustical Society decided to terminate the *Rivista Italiana di Acustica* (2015-1017).

The two European journals united under the name *ACUSTICA united with Acta Acustica* (1996-2001, Publisher Hirzel Verlag). The journal then changed its name to *Acta Acustica united with ACUSTICA (AAuA, 2002-2019)*.

Some countries kept publishing an acoustics journal: Poland with *Archives of Acoustics* (1976-) and Romania with the *Romanian Journal of Acoustics and Vibration*

(2004-). In Fig. 2, the number of article publications is compared between *AAuA* and *JASA*, during the years after 2007, when *AAuA* was well established. During the same period as that of Fig. 1, the number of articles in *JASA* doubled, while that in the European journal grew by 50%.

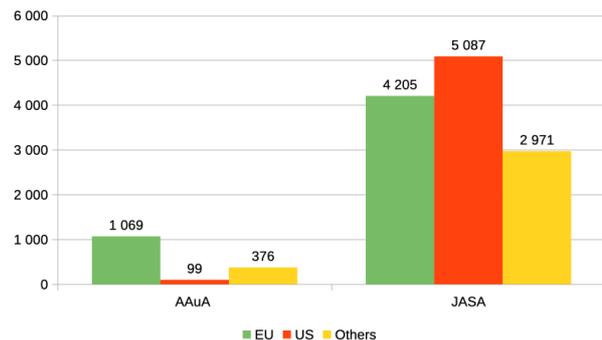


Figure 2. Number of articles during the period 2007-2019 in *AAuA* and *JASA*.

The main feature is the growing international nature of *JASA*. Apart from the effect of increasing number of *JASA* paper from China, 41% and 34% of the articles published in *JASA* are written by American and European scientists, respectively. Another feature is the preference of European authors for *JASA*: the number of European articles in *JASA* is 4 times that in *AAuA*. *JASA* is now the premium peer reviewed international broad-spectrum journal in acoustics. Success breeds success. We regret that the European Commission can financially support scientific conferences, but not journals or scientific societies. However, the orientation of the EC towards open science led to another important and positive change for the European journal.

4. ACTA ACUSTICA TODAY, THE TRANSITION

Before 2019, CD ROMs and paper versions of *AAuA* were available, in particular for libraries. Up to 2019, the EAA provided free access to the electronic version of *AAuA* for all individual members. This was an important step towards the open access model that was recommended by the European Commission, under the so-called [Plan S](#). Unanimously, the EAA General Assembly decided in 2016 to go open access. It also decided that it would transfer financial support to its members as readers, to the members as authors. Additionally, three choices were made: i) coming back to the name *Acta Acustica*; ii) changing the Publisher to EDP Sciences, iii) negotiating with Hirzel the purchase of the archives of *ACUSTICA* and *AAuA*. The latter was

done thanks to the support of the French [National Fund for Open Science](#), in the framework of the EAA project [Documenta Acustica electronica](#) (DAEL). The project aims to collect many documents of various kinds, including European journals in different languages with an automatic English translation (thanks to e-translate).

Fig. 3. shows the number of articles published during the last three years of *AAuA* and the first three years of *AA*. The transition to open access and the introduction of Article Processing Charges explains the diminution of the number of articles published, in particular for authors outside Europe. The number of articles signed by European authors was 43% of the article total before the transition. For *AA*, the percentage is 19% of the number of articles published. An aim for the new journal is to reach the figure of authors outside Europe for *AAuA*.

A [recent editorial letter](#) [2] provides many other interesting figures concerning *Acta Acustica*. As an example, the 3 countries with the highest number of articles published in 2022 were France (31), Germany (26) and China (18). The growth of the number of articles from China is particularly significant.

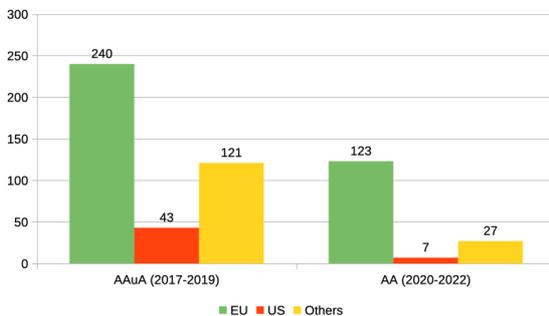


Figure 3. Number of articles during the period 2017-2019 in *AAuA* and 2020-2022 in *AA*.

5. CONCLUSION

The present paper focuses on broad-spectrum peer reviewed acoustics journals, which are the property of scientific societies. The intricate story of the unification of the national acoustical societies is a reflection of the 20th century in Europe. A consequence is the difficulty in building a scientific journal owned by a learned society, able to compete with the American journal. This is an enduring challenge: *JASA* built a real international journal progressively in about 50 years.

The present paper leaves aside the issue of citation metrics, because of the complexity of the history of

AAuA, then *AA*. Although the journal was continuously indexed in these major databases, it was a great satisfaction when *Acta Acustica* received its first Impact Factor of 1.355 last year under its new name (Clarivate Web of Science) and a Cite Score of 2.5 (Scopus, Elsevier). Despite the limits of these metrics, this is an encouragement.

A kind of stability is now reached by *Acta Acustica*, This could be reinforced by enlarging the Editorial board and by convincing all European acousticians that the open access publication model is preferable. *Acta Acustica* is a rigorous and international journal, and it can become even more attractive.

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7. REFERENCES

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