Education in acoustics at the Technical University of Denmark

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Introduction

The Technical University of Denmark (DTU) was founded in 1829 by the Danish physicist Hans Christian Ørsted. DTU is the largest technical University in northern Europe, with about 6000 students, 600 Ph.D. candidates, and 1250 researchers. The section Acoustic Technology is part of one of the 15 departments at DTU. Currently, the staff at AT consists of 8 teachers, 5 researchers on external grants, 2 visiting scientists, 13 Ph.D. students, 4 visiting Ph.D. students, and 5 administrative and technical staff members. In 2000, an M.Sc. Programm in Engineering Acoustics was established at DTU. 20-25 M.Sc. thesis projects per year run within this programm.

Study plan in Engineering Acoustics

All courses are given in English. The M.Sc. programm corresponds to two years full time study with the following requirements (and options). A total of at least 120 ECTS must be reached:

- 25 ECTS, from the list of "general competence courses" (Partial differential equations, Fundamentals of Acoustics, Acoustic Communication)
- 30 ECTS, three out of five of the "technological specialisation courses" (Electroacoustics, auditory signal processing, architectural acoustics, advanced acoustics, sound and vibration)
- 30 or 35 ECTS from the master thesis of a topic within engineering acoustics
- 35 or 30 ECTS from other (freely chosen) specialization or elective courses (e.g., advanced modeling, statistics, signal processing, finite element methods)

An overview about the acoustics courses currently offered at DTU is given in Fig. 1. In addition to the 13 weeks courses during the semesters, 3-weeks courses are offered (on "Technical audiology", "Advanced loudspeaker models", and "Environmental acoustics") in January or June. These courses are more focused on experimental work and concentrate on special projects.

Teaching concept

In the main (13-weeks) courses, the teaching takes place in two 4-hours modules per week, as indicated in Fig. 1. Typically, each week considers a particular topic and combines theoretical background and experimental lab work. Alternatively, in some courses, the theory covering the different topics of the whole course is presented in the first few weeks, followed by project work throughout the remaining part of the course.

Typically, researchers and/or teachers from other Universities or from industry are invited to give lectures on their area of expertise. This broadens the spectrum of topics covered in the individual courses.

In general, the teaching activities at Acoustic Technology are mainly within the areas of research; i.e., there exist considerable expertise in the different areas of teaching. This makes it possible for the students to continue with research (e.g. in terms of a Ph.D. project or a special project as a research assistant) after their studies. The teaching areas which are particularly research active are: Transducer technology, acoustic measurement techniques, numerical acoustics, measurement and modelling of sound insulation, room acoustic modelling, building acoustics, structure borne sound, psychoacoustics and speech perception, auditory modelling.

The facilities include two anechoic rooms, four reverberation rooms, four double walled listening booths, scale models of concert halls, scale models for studying outdoor propagation, and a standardized IEC listening room.

Example course: Auditory signal processing and perception

In this course, each week considers a particular topic and consists of a lecture block (plus problem solving) and lab work. The lab work takes place in groups of preferably three students. Typically, 35-40 students participate in the course. The students within a group might have different background (e.g., acoustics, signal processing, audiology). For each lab exercise, a report must be handed in within 10 days. The final evaluation is based on the lab reports (weighting 1/3) and an individual oral exam (weighting 2/3).

The course consists of the following topics and focus areas: (i) Basic concepts of digital signal processing (first two weeks), (ii) signal detection theory and psychoacoustic measurement methods, (iii) cochlear transformation and basilar-membrane models, (iv) frequency selectivity and masking, (v) perceptual consequences of hearing impairment, (vi) temporal processing and perception of fluctuating sounds, (vii) binaural and spatial hearing, (viii) loudness and intensity perception and coding, (ix) speech perception and processing and intelligibility of speech, (x) neural signal processing and neural modelling, (xi) auditory-

Semester	Course number and name	Group	ECTS
Sep - Dec	31200 Fundamentals of Acoustics and Noise Control	Tue: 8-12	5
	31230 Acoustic Communication	Mo: 8-12 Thu: 13-17	10
	31220 Electroacoustic Transducers and Systems	Wed: 8-12 Wed:13-17	10
	31270 Sound and Vibration	Tue: 13-17 Fri: 8-12	10
	31606 Signals and Linear Systems in discrete time	Thu:13-17	5
January	31221 Advanced loudspeaker models	January	5
	31232 Technical Audiology	January	5
Feb - May	31236 Auditory Signal Processing and Perception	Mo: 8-12 Thu: 13-17	10
	31260 Advanced Acoustics	Mo: 13-17 Thu: 8-12	10
	31240 Architectural Acoustics	Tue: 13-17 Fri: 8-12	10
	31661 From Biology to Technical Neural Systems	Tue: 13-17 Fri: 8-12	10
June	31250 Environmental Acoustics	June	5

Figure 1: Overview of the current courses within the M.Sc. Programm in Engineering Acoustics at DTU. Most courses (those with 10 ECTS credit points) run during the 13-week period of a semester, and take place in two modules of 4 hours each week. In addition, several project-oriented focus courses run over 3 weeks (in January or June), which complement the more fundamental main courses.

evoked potentials and (xii) basics of brain imaging methods (such as magnet resonance imaging).

The lab work (listening experiments, simulations and calculations) is mostly performed using Matlab. Of particular interest for the students has been, for example, the simulation of the transformation of sound through the inner ear, the cochlear. With PSpice the students implement an electrical circuit (a transmission-line) that simulates the frequency-selective processing in the cochlea. In a later exercise, the students estimate the shapes of their own auditory filters (using perceptual "notched-noise" masking experiments) and compare them with the results obtained from the transmission line simulations. In another exercise, the role of audio-frequency and modulation-spectral content on speech intelligibility is investigated in different acoustical environments. The results are linked to the established concepts of the articulation index, the speech intelligibility index, and speech transmission index.

Other technological specialisation courses

In the following, some of the topics of the other technological specialisation courses with the engineering acoustics programm are briefly described. Each of theses courses correspond to 10 ECTS.

"Electroacoustic transducers and systems" covers (i) analogies between electrical, mechanical and acoustical systems, (ii) microphones (e.g., condenser microphones, dynamic microphones, pressure and gradient microphones, and the principles of operation and equivalent networks), (iii) loudspeakers (principle of operation and equivalent network, effects of loudspeaker enclosures, loudspeaker systems, radiation impedance and efficiency), and (iv) audio coding (e.g., masking effects and MP3 coding).

The course "Advanced acoustics" covers (i) the fundamentals of acoustic wave motion, (ii) the radiation of sound (by point, cylindrical, spherical and plane sources), (iii) the classical modal theory of room acoustics, (iv) statistical room acoustics and the diffuse sound field, (v) sound intensity and its measurements, (v) fundamentals of active noise control, and (vi) near-field acoustic holography.

In the course "Architectural acoustics", (i) sound radiation from plates, sound reflection, scattering, diffusion and absorption, (ii) room acoustical measurement techniques, (iii) an introduction into subjective room acoustics, (iv) high sound insulation in buildings, (v) room acoustic simulations with a computer model (ODEON), and (vi) 3D sound and virtual acoustics, and statistics of diffuse sound fields are studied in detail.

The "Sound and vibration" course covers (i) vibration and sound waves in structures, (ii) bending waves in beams and plates, (iii) vibro-acoustic measurements techniques, (iv) models for damping and losses, (v) vibration isolation and damping, (vi) design principles for noise and vibration control, and (vii) active control of structureborne sound.

Summary

The international M.Sc. Programm in Engineering Acoustics at DTU covers a broad range of areas within acoustics. The teaching concept is to combine modules of lectures with intense experimental lab exercise work. The teaching activities are within the areas of research such that students can continue with research projects after their studies. Traditionally, the connection with the Danish industry has been strong, both in terms of teaching and research (e.g. M.Sc. projects and industrial Ph.D. projects).