Dr. Per V. Brüel –100 Years

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Running a business is about having fun.
Having fun is the best way to use your skills.

Figure 1. *Dr. Brüel at 100.*

Dr. Per Brüel (**Figure 1**) celebrated his 100th birthday on March 6, 2015.[1] For more than 75 years, Dr. Brüel was in the forefront of acoustic measurement techniques and analysis. During this time, he played a substantial role in acoustics as an engineer, a visionary inventor, a founder of a major global corporation, an enthusiastic pilot, and an explorer who personally pioneered new markets. And, as a scientist, he had a major influence on research and development in acoustics at university laboratories and at companies all over the world. Through development and production of high-quality instruments for nearly all kinds of acoustic measurements, Dr. Brüel had a decisive influence on the high standard of acoustic measurements of today and on our present knowledge of acoustical phenomena.

All acousticians have been influenced by Brüel's work because it gave them the advanced tools for their own research and development. Sound and vibration measurements today depend on the technology and advanced instruments developed by Brüel & Kjær, the company that Brüel founded in 1942 along with his partner, Viggo Kjær (1914–2013). This technology has an impact on communication; on air, ground, and sea transport; on environmental protection; on entertainment; on a broad variety of industrial processes; on human health protection; on energy production; and on noise abatement in residential properties and areas.

Per V. Brüel was born in 1915 in Copenhagen, the eldest son of Gustaf and Else Brüel. His father was a forester, and it was the family tradition that the eldest son should also be a forester. Per did not like the idea of becoming a forester, creating a big family scandal. Therefore, when he grew older, he was sent away to become a blacksmith. Fortunately, the manager of the power station where Per would be educated felt that a blacksmith was not the right education for Per and that he should go to the university. He received his high-school certificate in 1933, which gave him access to the Technical University of Denmark (TUD). Per's particular interests during his studies at the TUD (1933–1939) were electronics, aerodynamics, and acoustics. Per received his MSc degree from the TUD in 1939. Because his professor, P. O. Pedersen, who was also president of TUD, particularly looked

[1] *We are saddened that Dr. Per Brüel passed away on April 2, 2015.*

for bright and highly qualified students like Per, he chose Per to become his assistant. Per started working on sound transmission through walls. Later on, Pedersen suggested that Per should write a doctoral dissertation (the Dr techn) on acoustical impedance measured using a standing wave tube. The work on the doctoral dissertation took place over the subsequent years.

In September 1939, the Germans invaded Poland and the Danish army was called in. This included Per Brüel, who, as an electronics engineer, was transferred to a laboratory tasked with making radio communication equipment for armored cars. At this laboratory, Per, in his free time, built the world's first battery-operated acoustic analyzer with a constant relative bandwidth. The analyzer color was strongly influenced by the military, with a light-green front plate and a dark-green box. These colors still characterize instruments produced by Brüel & Kjær A/S.

After the German occupation of Denmark on April 9, 1940, Per returned to work with Professor Pedersen and continued work on his doctoral dissertation. Per strongly admired Pedersen as a key person in all acoustics in Denmark, but unfortunately Pedersen died in 1941. Per now became involved in acoustics of buildings as an assistant to Professor Chr. Nøkkentved, who was responsible for building the new Danish Broadcasting House. This job gave Per a deeper knowledge of room acoustics and sound absorbers and permitted him to work on his doctoral dissertation. In 1942, it was decided not to finish the Broadcasting House as long as the Germans were in Denmark. This finalized the work for Per in Denmark for a while.

He had, however, maintained a cooperation with his friend from his studies at the TUD, Viggo Kjær, and they founded the company, Brüel & Kjær, which in 1946 became a limited (A/S). But Per Brüel and Viggo Kjær both felt that they needed more industrial experience to be gained from work in other companies and they did not want to do work for the Germans.

While Viggo Kjær stayed in Denmark to gain experience in other companies, Per went to Sweden because he felt that their future main market would be Sweden. In Stockholm, Per became head of the acoustics department of Höganäs-Billesholm, working with sound absorption panels. At the beginning of 1944, Per was invited by Chalmers University in Gothenburg, Sweden, to establish an acoustical laboratory. Thus, he worked in building acoustics from 1944 to 1947, with objects like sound insulation, sound transmission, and

Figure 2. *Dr. Brüel as the pilot.*

acoustics in concert halls. One of Per's assistants at Chalmers University was Dr. Uno Ingard, who later became a famous professor of acoustics at MIT and another was a Danish colleague, Freimuth Larris, who developed the level recorder for acoustic measurements that became the main product of Brüel & Kjær for many years to come.

Per frequently visited Denmark during his time in Sweden. During the two last years of WWII, Per operated as a courier and brought messages to and from Denmark. These messages were frequently wrapped in his dissertation manuscript and were written on the same type of paper as the manuscript to look similar to it. Professor Niels Bohr, who had fled to Sweden, used Per as a messenger when he needed to have communication with Denmark. Toward the end of the war, the Germans became extremely nervous and had soldiers onboard the ferry between Sweden and Denmark. On his way back to the defense of this doctoral dissertation at the TUD, Per was stopped onboard the ferry by one of the Germans. After ruffling all the papers around in the cabin, the German discovered a crack in the heel of one of Per's shoes. He ripped off the heel and to be sure he also ripped off the heel of the other shoe. This brutal examination made Per very nervous, but the German did not find any "illegal" matters. For the defense of his dissertation the next day, Per turned up in his father's tuxedo and in shoes with glued-on heels. The defense went well and he got his Dr techn. The results of his dissertation with the title, *Application of the Tube-Method in Room Acoustics*, became a product that for many years was manufactured and sold by the company Brüel & Kjær A/S.

During WWII, it was difficult to get components for instruments to be produced in their company. Although Viggo Kjær was working in the radio industry and therefore had easier access to electronic components, the lack of copper wire was their biggest problem. However, one of their friends who was taking part in the resistance against the Germans turned out to be of great help to Brüel and Kjær. In the Bay of Køge, just south of Copenhagen, he cut away and stole about 1 km of the underwater telephone cable from the main communication line between the German occupation forces in Copenhagen and their headquarters in Berlin. This operation gave Brüel & Kjær enough copper wire for the rest of the war.

In 1944, Per had been offered and accepted an associate professorship at Chalmers University for three years. After the war, he stayed in Gothenburg for three days a week while the other days were spent in Brüel & Kjær A/S in Denmark. One instrument he particularly worked on in Sweden was an acoustic level recorder that was needed for measurement of reverberation time in rooms. This recorder was improved by the company and became one of their best selling products. As Per Brüel said about this instrument, "Without any doubt the level recorder, apart from being a good business, also had improved Denmark's position as a country, where they know something about acoustics." Difficulties with the longtime stability of microphones made it necessary to develop a simple and transportable calibration device. It was a pure mechanical construction consisting of two pistons steered by a polished cam disc.

Noise in wooden houses, in particular, step sounds, was also a subject studied at Chalmers University, where a special tapping device using 5 steel hammers knocking 10 times per second was developed. This device was later standardized by the International Electrochemical Commission (IEC) in Geneva.

Due to his many contacts in Sweden, Per Brüel was involved in establishing the Swedish Acoustical Society in 1945. The interest in acoustics and in noise abatement was developing very fast during Per's years in Sweden. In Sweden, they expected a boom in house building in Europe after the war, and development of sound and thermal-insulating building materials had a high priority, which was advantageous to his laboratory in Gothenburg.

After Per had returned to Denmark in 1947, he was the director of Danish Decca Navigator A/S for a year, where he established the Danish Decca system, but starting in 1948, he was employed full time by Brüel & Kjær A/S. The company had had a humble startup on a par with other companies such as Apple and Hewlett-Packard. Their first production site, after using the kitchen in Kjær's apartment, was a rented space in a dressmaker's workroom. The money was sparse and some limitations were imposed on Brüel and Kjær. As pointed out by Kjær, "We were happy to get room at Mrs. Dragby's. The only thing was that she didn't want any noise before 10 a.m. so we couldn't show up until then."

To finance the company start, Kjær sold his accordion and Brüel sold his Leica camera. This pattern of financial self-reliance characterized the company for the duration of Brüel's and Kjær's management. As Brüel once expressed, "I was scared stiff about borrowing money, if we did, we would die. It's far too expensive. We didn't want to be dependent on bankers; we wanted to be 100% self-financed."

In 1945, the company rented and moved into a stable in Lyngby, just 10 km north of Copenhagen. The 3rd partner in the management of the company, the technician Holger Nielsen, joined the same year. This improved the financial situation. In 1948, Brüel & Kjær A/S bought their first property, a wooden army barracks in Nærum, 15 km north of Copenhagen. These are the premises where the company is still located today.

The three directors shared the activities in such a way that Brüel was responsible for product planning, research, and sales, Kjær was responsible for development, and Nielsen was responsible for instrument production. As long as the market only comprised Denmark and Sweden, Brüel personally delivered the instruments to customers using his Nimbus motor bike.

When the market increased with the rest of Scandinavia and Europe, cars were needed, and in 1980, about 30 company cars were available. When the distance to customers increased with new customers outside Europe, "Brüel & Kjær Airlines" was established in 1956. The company eventually was the owner of a substantial fleet of aircraft, which made it possible for Brüel, who had a pilot's certificate for flying one- and two-engine airplanes, to make airborne deliveries to any customer who was located near a general aviation airport. In the mid-1980s, several employees in the company were asked to get pilot licenses to fly with Brüel due to the concern about his advancing age. Per finally solved this issue by hiring his flight instructor as his personal copilot. To the consternation of the passengers, the copilot was even older than Per.

When Brüel & Kjær A/S moved to Nærum, the partners made three commitments to each other. (1) All instruments should be produced in Denmark, (2) there would be no development for the military, and (3) the company should be self-financed and independent of any banks. The second commitment was because WWII had just ended. Because of this commitment, the company was able to sell instruments behind the Iron Curtain without any embargo during the Cold War.

The level recorder, used to measure sound level versus time, was not expected to be sold in greater numbers. Kjær was convinced that the company could not sell more than 50 units, and he and Brüel had an agreement that they should not produce anything that could not be sold in at least 75 units. Brüel felt that the company could sell 150 units, so he had to produce the first recorders in Sweden. Later the production was continued in the factory in Denmark, and the total number of level recorders produced and sold over 30 years, after being updated a number of times, was 25,000. Brüel felt that a reason for this sales success was a three page article published in the Journal of the Acoustical Society of America (Brüel and Ingård, 1949), and, of course, the worldwide need for such an instrument. [To view article visit: http://goo.gl/dv7Tpl].

Another successful line of equipment developed, manufactured, and sold by Brüel & Kjær A/S is the condenser microphone. The microphones available previously in the market had the drawback that they became more sensitive with age, gaining about 1–2 dB per year in sensitivity. They were based on a diaphragm clamped between an outer ring and the main housing of the microphone. The diaphragm had to be under stress all the time, but clamping it would permit the diaphragm to move very little due to temperature variation and thus change the sensitivity. This problem was solved by Brüel & Kjær A/S by directly bonding the diaphragm to the housing either through welding, hard soldering, or electroplating. This major improvement together with other improvements gave the company a position as the leading manufacturer of quality microphones with an export sale through 25 years between 5 and 9 million dollars US per year. The microphones were also used in precision sound level meters made by Gunnar Rasmussen, one of Brüel's oldest coworkers. This device was given the shape of a gin bottle to minimize reflection of the sound waves back to the microphone.

Noise-produced hearing damage had been an field of interest to Brüel. He found that the human ear has two time constants, a short one of 30–50 μs and a longer one of about 100–150 ms. This could explain why hearing damages start at higher frequencies, around 4–7 kHz, even if the noise level around 200–2,000 Hz is 20 dB higher. This explains why short duration but very intense hammer strokes will not be heard or measured with their full amplitude but that the nerves will be exposed to the full amplitude and will be damaged. The Institute of Acoustics in England awarded Brüel the Lord Rayleigh Gold Medal in 1975 for this discovery.

Brüel was also fighting for better weighting curves because it was found that the A-weighting was incorrect in the important frequency range of 2.5–8 kHz, where it gave 8 dB lower results. Per found that Karl Kryter's D-weighting curve (Kryter, 1970) was much more correct.

A few sentences by Per Brüel characterize his attitude toward the work and from the unofficial rules of conduct: "Running a business is about having fun. Having fun is the best way to use your skills. We want talented people who can think for themselves, who are creative and also a bit lucky. Employ good people; don't tell them what to do when they start work, because people will find that out for themselves, making them highly inspired." And about having fun, his vision statement is: "We shall have fun and we shall make money. On the other hand we shall not have so much fun that we do not make money, and we shall not make so much money that we do not have fun." These are the words of a charismatic and inspiring company director.

Brüel & Kjær A/S had an annual growth rate of about 10% in production, sales, and profit for many years, and the company became the "flagship" of the Danish electronic industry in the 1980s. In 1988, the yearly turnover was close to 800 million DKK (US$ 125 million) and the staff included 3,200 employees.

From the very beginning of the company, Per Brüel always considered the market for the company's products to be global. Moreover, his choice of new products to be developed has always been based on customers' need. Because the company from the beginning had very few competitors, Per rushed to fill in this competitive vacuum through marathon driving and flying trips to the European countries, to the United States, to Russia (visited the first time in 1950), and to China (visited the first time in 1953).

Per Brüel was charismatic, bright, and fast thinking, abilities he preserved to the present day. He was also a world-class engineer, who still could suggest surprising engineering solutions to sound and vibration problems. I first met Brüel in 1964 when he invited the participants in a NATO Advanced Study Institute on Underwater Acoustics and Signal Processing to visit the factories in Nærum. Per personally showed us around in the factory, and I was strongly impressed by his lively presentation of instruments and their qualities, his knowledge on sound and vibration, and his dedication to all aspects of acoustics. This meeting in 1964 led to a great friendship that developed over the subsequent years through travels to conferences and family parties.

Per Brüel was a member of the board of directors for Brüel & Kjær A/S from 1942 and to 1991, and he was a member of the board of directors for a great number of subsidiary companies in many countries. He was also a member of the Council for the Danish National Bank. His great interests in aviation made him obvious as a member of the Contact Committee for General Aviation, as chairman of the Council for Motorised Airplanes, and as a vice president for Federation Aèronautique Internationale. With Per's deep knowledge about aircraft noise, he contributed to ISO standards on this topic, and he was for many years a member of standardization committees for a long series of standards on aspects of sound and vibration. He also received the Aviation Cup for distinguished contributions to aviation (**Figure 2**).

Automobiles were also an interest of Per's. In fact, he took part in several car races for vintage cars. While Nielsen used a Jaguar, Per had a Fiat 500. When he was asked why he preferred the small Fiat to other more comfortable company cars, he replied that the comfort in a Fiat 500 was so poor that he could keep the car for himself because nobody in the company would ever ask him for a lift.

All Per's important scientific and technical contributions to sound and vibration over more than 75 years brought him recognition from many universities and scientific organizations. He was a member of the Danish Academy of Technical Sciences and a member of the National Academy of Engineering in the United States with the citation: "Development and production of precision acoustical and vibrational measuring instruments." In 1987, the American Society of Mechanical Engineers (ASME) established a "Per Brüel Gold Medal" for Noise Control and Acoustics. This medal honors Dr. Per Brüel for pioneering the development of sophisticated noise and vibration measuring and processing equipment. It is given in recognition of eminent achievement and extraordinary merit in the field of noise control and acoustics. He was also a Distinguished Member of the Institute of Noise Control Engineering of the United States. Moreover, he received honorary professorships and doctor degrees from many universities.

Unfortunately, Brüel & Kjær A/S started to have financial problems at the end of the 1980s. In July 1992, the company was sold to the German holding company AGIV. Far into the normal retirement age, Per Brüel started his new company, Brüel Acoustics. In the new company, Brüel continued his activities involving the development of instruments and of technologies for measurement of the masking of speech, the propagation of step noise, the intelligibility of speech, the sound pressure, and absorption coefficients, and he was fighting for getting the IEC standard for A-weighting of noise measurements abolished. Instead, the standard should be Kryter's D-weighting curve.

Dr. Per V. Brüel, who turned 100 years, preserved his legendary energy, and the strong admiration he enjoyed among acousticians all over the world for his many and decisive contributions to sound and vibration is unchanged.

Biosketch

Leif Bjørnø (pictured (right) with Dr. Brüel at 100th birthday party) Professor & Professor h.c., Dr. Phil. h.c., Ph.D., DIC. Born 1937 in Svendborg, Denmark. He was professor of Industrial Acoustics at the Technical University of Denmark from 1978 – 2000. He is a Fellow or Honorary Member of several international learned societies, and he has received honorary degrees, medals and prizes from a substantial number of universities around the world. He has been chairman or member of the board of directors for several industrial companies in Denmark and abroad, 1980-2013.

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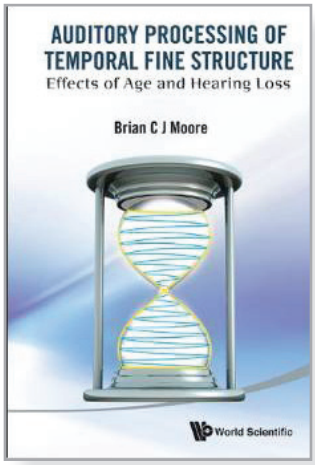
– Philip L. Marston, *Book Review Editor*



Auditory Processing of Temporal Fine Structure: Effects of Age and Hearing Loss

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Auditory Processing of Temporal Fine Structure: Effects of Age and Hearing Loss is a comprehensive resource that will be of great use to readers with a variety of backgrounds and purposes. The structure is logical, the references are very up-to-date, and the index and table of contents are practical and useful.

At the core of the book is the concept that signals can be represented in terms of an envelope (ENV) superimposed on the temporal fine structure (TFS). Furthermore, ENV and TFS can be considered at three levels: the physical signal itself (ENV-*P* and TFS-*P*), at a particular place on the basilar membrane or output of a cochlear filter (ENV-*BM* and TFS-*BM*), and in terms of neural representation (ENV-*N* and TFS-*N*).

The introductory chapter expands on these concepts comprehensively. This chapter is the longest in the book, and in some ways is the most crucial. Cochlear filtering, hair cell transduction, and the "active amplifier" system of the cochlea are all explained within the framework of ENV and TFS; at the levels of the physical signal, the pattern of vibration of the basilar membrane, and neural encoding. The way in which various pathologies of hearing damage and aging affect each of these mechanisms are then expanded on, with a great selection of classic and modern references. Finally, the chapter closes with "a list of (seven) possible ways in which hearing loss and ageing might affect the neural encoding of TFS."

Chapters 2–5 that follow go on to explain the role of TFS in perception for both normal-hearing and hearing-impaired listeners. There are chapters on masking, pitch perception, speech perception, and binaural processing, and all share some similarity in structure. Each chapter explains the role of TFS in normal hearing in each case, and then explains how pathology associated with aging or hearing loss affects TFS processing, and subsequently the perceptual ability under review. This structure is somewhat dense but thorough, and does have the advantage of being predictable, so that the reader using the book as a reference can confidently move between chapters. Although the included figures in the middle chapters all clearly illustrate various results and data, some concepts that are explained in text might have been more easily conveyed via a simplified diagram.

The treatment of pitch perception in Chapter 3 covers both the pitch of simple sine waves as well as complex sounds. The chapter starts from the very basic elements of pitch perception. It is interesting to reconsider the old place pitch/temporal pitch war within the ENV/TFS framework. Moore reviews a large literature demonstrating that for pure tones at low frequencies, TFS-N is the main factor contributing to pitch perception. At higher frequencies where there is no more phase locking, place pitch takes over. It would have been interesting to go deeper into other perceptual dimensions of pitch, such as spectral pitch, chroma, or brightness.

The final chapter is a useful overview of the book. It offers practical suggestions for how the ideas presented might be relevant for signal processing in hearing aids, as well as suggestions for how people might avoid the types of acoustic environments which are most detrimental for people who have low sensitivity to TFS.

The book has arrived at an interesting time in the worlds of hearing research and clinical audiology. As Professor Moore alludes to in his preface, there is an imperative for audiomet-

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