Psychoacoustics and Community Noise Impact Assessment

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Introduction

Although Leo Beranek's personal accomplishments in noise control and architectural acoustics may be better known, his direct and indirect contributions to research in psychoacoustics and community response to transportation noise have also been highly influential. Leo's solutions to specific technical problems often proved novel, trend-setting, broadly applicable, and thoroughly practical. Methods and analyses that Leo developed have not always been widely accepted initially, but have ultimately been recognized as technically valid and useful, and have established paradigms for technical progress in subsequent decades. His contributions may often be found at the center of spreading intellectual ripples in many theoretical and applied areas. Through his hiring and continuing technical and managerial support of BBN staff starting in the 1950s, Leo has become the intellectual grandparent of much subsequent work in transportation noise analysis, environmental noise impact assessment, and prediction of community response to noise exposure.

Improving Speech Intelligibility in Noisy Aircraft

Many engineers are content to craft narrow solutions to technical problems that others define and present to them. The breadth and depth of Leo's understanding of fundamental principles of acoustics permitted him to extend solutions that he devised to specific technical challenges to settings far broader than those for which they were initially developed. For example, as director of Harvard's Electro-acoustic Laboratory in World War II, Leo was presented with the challenge of improving the intelligibility of speech communication among oxygen mask-wearing crew members flying in unpressurized military aircraft. Conventional approaches to minimizing unwanted transmission of acoustic energy (adding mass and/or stiffness) were inapplicable in aircraft where very light-weight materials were essential.

Leo reasoned that a very fine fibrous material was needed to absorb unwanted sound in aircraft since friction between air particles at fiber surfaces causes sound energy losses. After observing that the surface area of fibers increases as their weight decreases, he persuaded Owens-Corning Fiberglass to develop means for manufacturing blankets of very small diameter fibers. This made it possible to design light-weight noise reducing structures in aircraft. Leo coined the term "anechoic"while working the problem, pioneered the application of absorption of acoustic energy by fiberglass wedges to anechoic chambers, and made it practical to extend Sabine's earlier discoveries about reverberation control to other architectural applications.

Leo went on to further facilitate voice communication in aircraft by working with manufacturers, and with U.S. and British military forces to rapidly build and buy specially-designed headphones. His wartime research interests in speech intelli-

Figure 1: *Karl Pearson, in BBN Los Angeles office, 1960s.*

Figure 2: *Karl Kryter and Dave Green*

gibility continued in later years by his first and subsequent generations of post-war hires at BBN, including Karl Kryter, Karl Pearsons, and Carl Williams (**Figure 1**).

Leo's Intellectual Responsibility for Developments in Other Fields

By the same token, Leo is indirectly responsible for facilitating technical progress in a wide variety of related areas of physical acoustics, psychoacoustics and community response research. Bill Galloway notes that in the early 1950s, Leo worked assiduously to attract MIT and Harvard faculty to BBN -even if only as part-timers - including Ira Dyer, Herman Feschbach, Ira Hirsh, Ken Stevens, Walter Rosenblith, and Francis Weiner, among others. BBN's hiring of J.C.R Licklider to lead its well-known pioneering work in computing was also indirectly responsible for a great deal of research on acoustic (and visual) signal detection and recognition by human observers, through the efforts of full and part-time BBN staff members, including John Swets, Ken Stevens, and Dave Green (**Figure 2**).

The epic book *A Culture of Innovation,* edited by David Walden and Raymond Nickerson, with chapters by nineteen long-time BBN people, covers an enormous amount of information on the early days of BBN's growth and development (Walden, D. and Nickerson, R., editors, 2011). This author had the privilege of contributing to one of its 22 chapters, Chapter 8 "Psychology at BBN from the mid-1960's" (Nickerson, R., and Fidell, S., 2011). The research in psychoacoustics and its applications in community noise control came from both the Cambridge and Los Angeles offices of BBN, in the early days as well as through the beginning of the twenty-first century.

Leo is likewise indirectly, but critically, responsible for fostering developments at BBN and dozens of its spinoff companies in a considerable range of human-related acoustic research and consulting fields. These include speech recognition, speech-to-text technology, early detection of high frequency hearing loss, distinguishing auditory from cognitive deficits in speech perception in noise, and documenting the effects of ambient noise on speech spectra in everyday communications. Leo's hiring of Bill Galloway in 1953 (**Figure 3**), Karl Kryter in 1957, and Ted Schultz in 1960 were similarly at the root of long sequences of research and development worldwide in community noise impact prediction. These developments continue to the present day, as evidenced by the current Final Draft of Revised First ISO/CD 1996-1 "Acoustics – Description, measurement and assessment of environmental noise – Part 1: Basic quantities and assessment procedures" (ISO, 1966). The document formalizes a systematic approach to deriving a dosage-response relationship for predicting the prevalence of a consequential degree of transportation noise-induced annoyance in communities, and for distinguishing the acoustic- and non-acoustic contributions to annoyance prevalence rates.

Leo's Contributions to Assessing Individual and Community Impacts of Transportation Noise

The specifics of Leo's early contributions to understanding aircraft noise effects on communities are worth summarizing in detail since they typify his long lasting influences in this and related technical fields.[1] In the fall of 1956, Leo was contacted by the Port of New York Authority about a request from Pan American Airlines to begin operating the Boeing 707 jet in two years at Idlewild Airport (now JFK). The Port had established a policy in 1951 of prohibiting operations at its airports by any (in practice, jet-powered) aircraft that were noisier on takeoff and landing than existing four engine, propeller-powered passenger aircraft. The aircraft manufacturers had interpreted the Port's policy as "no greater overall sound pressure level." The Port, on the other hand, had already been sued over the noisiness of aircraft operating out of its Newark airport.

It was readily apparent to even casual listeners that the spectra of jet and propeller-powered aircraft were dissimilar. The Boeing 707 passenger aircraft, which was one of the first generation of commercial jets, was an adaptation of a military tanker, equipped with four commercial versions of Pratt and Whitney's J57 engine. The engine was a straight axial flow turbojet. Early versions produced 13,000 pounds of thrust with a very high exhaust gas velocity. The engine was exceptionally noisy, since jet noise is proportional to the eighth power of exhaust gas velocity. The engine had been designed for use in military aircraft, ranging from "Century-series" fighters (F-100s, F-102s, F-105s) to U-2s, with little or no regard for its noise emissions. In addition to the broadband noise created by its exhaust, the engine was a "screamer,"emitting piercing tones from the front of the nacelles in which it was mounted, in precisely the spectral region to which human hearing is most sensitive.

Boeing had conducted extensive programs to develop sound suppressors to reduce the overall sound pressure levels of the 707's noise emissions - but not in the frequency range that was most annoying. When Boeing continued to insist that the noisiness of the 707 was no greater than that of large passenger aircraft already in revenue service, the Port sought Leo's help in measuring its noise emissions.

Figure 3: *William "Bill" Galloway, June 1960.*

Informal listening tests were arranged in Seattle, at which the Port Authority concluded that 707 overflights at altitudes comparable to those at which the aircraft would overfly homes near New York's (then) Idlewild Airport were intolerably noisy, and that the aircraft would be unsuitable for use at Port Authority airports. In early 1957, Leo supervised field measurements in Seattle in which both Boeing and BBN engineers made calibrated recordings of 707 flyovers, and later noise measurements in New York of a great many propeller-driven transport aircraft take-offs. Aircraft noise measurements were also made in France and England of the take-off noise created by Caravelle and Comet 4 jet transports, two other early commercial jet liners.

Four sets of controlled listening tests were eventually conducted, from which it was possible to infer how much noise reduction was required to render the 707 no noisier than large propeller aircraft. It was estimated that jet noise would have to be reduced by 15 dB to be judged no more annoying than the noise of large, four engine propeller aircraft. Karl Kryter and Karl Pearsons developed the "Perceived Noise Level" scale to represent the frequency-weighted noisiness, rather than the broadband acoustic energy, of sounds. A demonstration recording was also prepared that permitted listeners to hear for themselves the differences among take-offs by jet and propeller transport aircraft.

To Boeing's dismay, the demonstration recordings were played for airport administrations in Germany, France, and the Netherlands, potentially damaging the jet's sales pros-

1 Readers interested in further detail are referred to Chapter 6, "Muffling the Jet Age," of Beranek (2008).

pects. Boeing attempted by various means, including ad hominem arguments and threats of litigation, to impugn the technical credibility of the demonstration recording and the measurements on which it was based. BBN in general, and Leo in particular, were demonized within the air transportation industry. In July of 1958, Boeing conducted its own listening tests, in which propeller and jet-powered aircraft overflew a house in suburban Seattle. Boeing employees served as test participants, rating the relative loudness of the overflights. The results of Boeing's field test confirmed the BBN estimate of a 15 dB differential in noisiness, but were never publicized.

A meeting was then arranged in Seattle between Boeing management, presidents of major airlines, and Port of New York Authority personnel, at which Leo was given an opportunity to present, explain, and defend BBN's methods and conclusions. According to Bill Galloway, at the end of the discussion the issue was summarized succinctly by the president of Boeing's airplane division as *"Dr. Beranek, you have convinced me that we have just spent eight million dollars on the wrong problem."*

Figure 4: *BBN/LA staff (Harry Himelblau, Patrick McCarty, and Dave Keast, June 1960, with the system built at BBN/LA to process vibration data tapes recorded during launches of the Titan II Missile from Cape Canaveral.*

By late summer of 1958, rumors of imminent litigation against the Port Authority and BBN by Boeing prompted the preparation of two lengthy and highly detailed technical reports describing the objective and subjective measurements of the relative noisiness of Boeing 707-120 and Comet 4 aircraft. Leo personally supervised production of 1,000 copies of each report, released in early October. The New York Times account of the Port Authority's establishment of a Perceived Noise Level of 112 dB takeoff noise limit stated that "Pan American says that if such operating conditions were to become permanent restrictions at Idlewild and other airports throughout the United States and the world, they would impose a severe, unjustifiable and, therefore, discriminatory handicap on all aircraft."

In hindsight, Pan American's and Boeing's positions were short sighted, technically incorrect, and motivated primarily by the companies' short-term commercial interests. To those with long memories, Boeing's proud claim in 2006 that the noise emissions of its 747-8 aircraft (10 dB lower than recommendations of the International Civil Aviation Organization (ICAO) demonstrated the company's efforts "to design the 747-8 with the community and environment in mind" may seem incongruous. Without Leo's efforts at the dawn of the jet transportation age in opposition to industry preferences, it is unlikely that the present worldwide aircraft noise regulatory framework would have evolved as far and as quickly as it has.

BBN staff hired directly by Leo and/or with his active encouragement continued to develop aircraft noise measurement and modeling techniques throughout succeeding decades. Bill Galloway and his co-workers in BBN's Los Angeles office worked extensively throughout the 1950s and 1960s with the U.S. Air Force in standardizing methods for measuring aircraft noise. One such example is the vibration measurements of Titan II missile launches from Cape Canaveral (**Figure 4**).

They also developed the first aircraft noise exposure modeling software ("NOISEMAP"), and strongly influenced the U.S. Environmental Protection Agency in its interpretations of the Noise Control Act of 1972. They were also heavily involved in standardizing methods for automotive traffic noise measurement for DOT agencies, and were closely involved with Department of Defense agencies in aircraft noise assessments mandated by the National Environmental Policy Act of 1970.

Ted Schultz's 1970s work for the Department of Housing and Urban Development is particularly noteworthy. As described by Fidell (2003), Ted demonstrated (Schultz, 1978) that the results of social surveys conducted in disparate cities and languages on the effects of aircraft and surface transportation noise could be interpreted in common terms, and usefully summarized in the form of a dosage-response relationship. Successors to this relationship (cf. Miedema and Vos, 1998; Fidell and Silvati, 2004; Fidell et al., 2011, inter alia) are relied upon today to characterize noise impacts for purposes such as planning transportation infrastructure projects, and for determining eligibility for federal funding of large-scale noise mitigation projects.

Like Leo's earlier work for the Port of New York, Ted's dosage-response relationship was extremely controversial for several years, to the extent that some feared that BBN's commercial interests might suffer. Leo dismissed the concern by observing that it was impossible to be a leader in a technical field without encountering controversy. He was also critical, in conjunction with other BBN senior management, in fostering a corporate culture that concentrated on hiring talented staff and encouraging them to pursue their own professional careers, rather than company-mandated business goals.

Acknowledgments

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Biosketch

Sandy Fidell. BBN hired Sandy Fidell fresh out of graduate school in 1968 to work in its Los Angeles office with Karl Pearsons and David Green on NASA-funded research on the influence of phase relationships on the annoyance of impulsive sounds. His initial professional association with Leo Beranek began shortly thereafter, in an assessment of sonic boom environmental impacts. He continued to work at BBN on transportation noise, acoustic detection, and an unexpectedly wide variety of psychoacoustic and other projects for the next 33 years. He formed Fidell Associates after retiring from BBN, where he continues to till many of the same consulting and research fields.

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Off the Ice

In 1966, I was a young geophysics student and had just spent a season in Antarctica digging ice pits, measuring glacial depth, and making various seismic and other geophysical observations, and I was preparing to head back to "the ice" to spend a second season making geomagnetic measurements while flying over uncharted territory. Yet apart from my technical interests, performing and listening to music had played a major part in my life. So while pursuing my technical engineering pursuits, I found I had room for one more course; I chose one on electro-acoustics taught around Beranek's 1954 *Acoustics* text. I found it fascinating and then obtained a copy of *Music, Acoustics and Architecture* (1962) to take with me to the ice.

About half way through reading this, I realized from Leo's example that it was conceivable to combine music and engineering interests in a consulting career in architectural acoustics. Upon my return from the ice I applied for a job at BBN, and the rest is history. After fifty years in consulting, I am immensely grateful for that opportunity, and for Leo's central part in stoking my initial acoustics interests through his writings.

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Business Leader, Innovator, and Role Model

My own comments about Leo are drawn not from his acoustics acumen, but from my years working with him at Bolt Beranek and Newman, Inc. (BBN).

Leo served as BBN's President and CEO until 1969 when he left the company to become CEO of Boston Broadcasters Inc., owner of one of the three major broadcast television stations in the Boston area. Samuel Labate became BBN's second President then, and I followed Sam into that position in 1976. From 1966, the year I joined BBN, until I retired in 1995, my work with Leo primarily involved the non-technical aspects of BBN's business, including the creation of new business ventures, technology licensing, business development, and general management.

Over the years as I worked with Leo, my strongest impressions of him center not only on his obvious intellectual gifts, but also on his tremendous ability to focus, his enormous energy and drive, his self-discipline, and his tremendous capacity for hard work. I remember him telling me that he would generally wake up every day at 4:30 AM so that he could plan, organize, and prepare for his work that day.

I would be remiss not to make note of the important role I observed Leo play in expanding BBN's business into the fields of computer and communications network technology. In expanding beyond acoustic technologies, Leo always emphasized the critical importance of seeking out and recruiting only the best and brightest people in their respective fields. There is no doubt that following this guiding principle was one of the key reasons that BBN came to be generally recognized as a leader in acoustics, computer and communications network technologies. At its peak, the company employed more than 3,000 people, many of whom held advanced degrees in their respective fields of interest.

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Check that Reverberation Time

Every year, we teach a class for the Architectural Technology program on how to appreciate music in performance halls for the Graduate Program in Architectural Acoustics at Rensselaer Polytechnic Institute (RPI). We hold this class in the Troy Music Hall (TMH). In April, 2006, I asked Leo to present a lecture to this class. The hall and its history were first introduced to the students by Laura Kratt, the Director of TMH. That morning, the class was scheduled at 10:00 am so I went to pick up Leo at his hotel lobby around 9:30 am.

When I met Leo, he said to me, "I am not feeling comfortable," since he didn't know anything about the hall; it is not in his book Concert halls and Opera Houses. I had my laptop with me, so I showed Leo some of our recent acoustical measurements, including a chart of reverberation times as a function of frequency; the data showed a range between 1.8s and 2.6s. In the middle frequencies, it is about 2.4s. After looking through these results, Leo said he now felt comfortable, and went with me to hall to give his lecture.

An elevator from the Troy Savings Bank Lobby led us directly into the Troy Music Hall; Ms. Kratt was waiting for us, and she welcomed Leo (who wore hearing aids at that time). Leo briefly exchanged some words of greeting with Laura, and then turned around to me, and said—without missing a beat—"Ning, this hall doesn't sound like it has an RT of 2.4 seconds." Laura confirmed to Leo that he was right, and that the hall had been set up for the pop-music mode with additional absorption brought into the room. Leo's hearing, even with his hearing aids, was sharp enough to sense the actual reverberant properties of the Hall in an instant.

Ms. Laura Kratt (right), Director of the Troy Saving Bank Music Hall giving Leo a tour and a briefing on the history of the Troy Saving Bank Music Hall, accompanied by Dr. Ning Xiang, Chair of the Graduate Program in Architectural Acoustics, RPI.

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Leo Beranek—a Mensch

A young man—a recent UCLA graduate—finally reaches his goal of becoming an "acoustical consultant," and is offered an opportunity to join the extraordinary firm of Bolt Beranek and Newman. When he got the job, he declared from the onset that he would at some point move back to Europe.

When the time to leave the United States had come, Leo Beranek offered his support. Most people are not aware that Leo was then accused of helping valuable BBN'ers set up potential competing businesses and was therefore admonished for doing so. In spite of these concerns, Leo never gave up his support.

In fact, for the last 42 years, Leo's backing of this upstart has been powerful, simple, and friendly. He has helped him in many ways: technically, scientifically, morally, philosophically, and even materially when absolutely necessary. In hindsight, this beneficiary realizes that the presence in his life of such an individual gave him the tools to overcome many of life's obstacles.

The long term result is revealing not only for this single individual but also collectively for the profession. In France, in the early 70's, acoustical consulting was practically non-existent; only a few individuals practiced applied acoustics, generally via the national radio system. The modest introduction of BBN principles and methods, with the unflagging endorsement of Leo Beranek in happy and unhappy times, has transformed the profession. Today, in France, most of the competent and constructive acoustical consultants, directly or indirectly, and most often unconsciously, have been influenced positively by Leo Beranek. And I am sure that Leo's generous personal support and its ripple effect to our profession has been received in a similar manner throughout the world.

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A Genuine Mentor, in Japan

Since 1989, Dr. Beranek has visited Japan over 20 times and worked for a period of 13 years until 2001 on seven performance hall projects as an acoustic design consultant together with my acoustic team. The halls are Hamarikyu Asahi Hall, Mitaka Art Center Hall, New National Theater (NNT) Opera House, NNT Drama Theater, NNT Experimental Theater, Tokyo Opera City Concert Hall, and Daiichi Seimei Hall. All of these halls are of premium importance to Japan. Dr. Beranek always came up with innovative ideas and helped us create halls that are endowed with high acoustic originality. These halls are now loved by music-related people and music fanciers, and they are regarded as the pride of Japan. The reviews and studies achieved through these projects were published as seven JASA papers, and the results have been presented widely to the public in an objective and professional manner. Leo has made considerable contributions to the concert hall projects in Japan and the Japanese musical culture through his work. "Your actions inspired us to dream more, learn more, act more and become more. You are a genuine mentor."

Leo in Japan working with colleagues at concert hall model.

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ASA's 75th Anniversary New York City, 2004

I remember the call from ASA President Bill Hartmann in 2001 as though it was yesterday. We exchanged pleasantries while I pondered what task Bill would request I undertake. Shortly into the conversation, Bill ventured that he was hoping to convince me to take on a special assignment for the ASA—co-chair of the 75th Anniversary Celebration to be held in New York in 2004. As Bill talked, I had a growing sense that I just couldn't accept because of current commitments. But then Bill dropped a magic word — Leo, as in Beranek. I would be Co-Chair of the 75th Anniversary Celebration with Leo Beranek! How could I say no?

Quintessentially organized and efficient, Leo was a pleasure to work with. He suggested we assemble two stellar committees, east coast (Leo's) and west coast (Pat's), to create the exciting events we envisioned — a celebratory Banquet and a 75th year Celebration film to be shown at the Banquet (akin to ASA's 25th Celebration film). The film would focus on interviews of past ASA Presidents, a "Look to the Future" Plenary Session with presentations from young up and coming ASA stars, a Champagne Reception for ASA Fellows, and numerous acoustic tours, displays, and side trips in NYC. Leo was a master at both the big picture planning and the little picture attention to detail – from negotiating with New York's union laborers, to timing the walks between venues, to considering how we would honor past Presidents without offending any, to purchasing my favorite Champagne (Veuve Clicquot) at a price never experienced prior to or since — Leo exhibited exquisite skill and superb humor.

I recently re-read Leo's 21-page summary of the planning and execution of the 75th Celebration for ASA's "Time Capsule." It reveals the incredible treasure the ASA has in the scientist/artist/man that is Leo Beranek. Happy 100th Birthday, Leo!

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