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2aED7. Teaching principles of outdoor sound propagation using football game measurements

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As part of a sound system evaluation at Brigham Young University's football stadium, measurements were made before and during games by an upper-level undergraduate acoustics class. The measurement experience provided significant training opportunities for the students. Teams of students used sound level meters to make recordings at numerous locations both inside and outside the stadium. These measurements were then correlated with data from stationary microphones placed near the field. From the data, the predicted slow, A-weighted equivalent levels in and around the stadium were calculated relative to a sideline location. Straightforward outdoor sound propagation prediction methods involving geometric spreading, atmospheric absorption, barriers, etc. were successfully used to validate the measured data within 1-2 dB at many locations, including one in the foothills to the southeast of the stadium at a distance of approximately 2.7 km. The students appreciated the hands-on experiences gained by participation in the measurements and analysis.

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INTRODUCTION

When Physics 461, "Introduction to Acoustics" was developed at Brigham Young University (BYU) five years ago,[1-3] the intent was to provide advanced undergraduates exposure to principles and mathematics of acoustics coupled with realistic homework problem sets and lab exercises. Course instruction and activities were designed to hopefully provide students with resumé-building skills and experiences that would prepare them for research, internships, and/or post-undergraduate degree employment.

As part of the overall "hands-on" philosophy, students have had the opportunity to carry out "unscripted" measurements that were needed to solve an actual problem during multiple semesters. The BYU Acoustics group often receives requests for help on local problems, and we decided to try to use one or more each year as a learning experience for the students. One example involved community noise measurements of a skate park in order to assess neighboring property owners' complaints.[4] These activities take the idea of an "interactive lecture demonstration,"[5] one of the proven methods to promote active learning in physics education research, to a higher level. In the process, students find a direct context for applying the principles learned in class, which they appreciate. In addition they engage in both planning and discussing the measurements more fully because of the unscripted nature of the problem, in contrast to a prepared lab. Effective involvement and implementation is a challenge given the real-time, variable nature of the requests, but the positive experiences and student responses seem to merit the additional effort and course content modifications.

During the past two years, members of the 461 class have participated in making measurements in and around the BYU football stadium on game days. The primary purpose has been to quantify the performance of the sound system inside and outside the stadium. This paper outlines the measurements taken and shows how the principles taught during the class were incorporated to yield a comparison between the measurements and the model for outdoor sound propagation.

DESCRIPTION OF MEASUREMENTS

Lavell Edwards Stadium is located at the north edge of the BYU campus and has a seating capacity of 63,470.[6] In addition to approximately six (American) football games played each fall, it also is home to the Stadium of Fire, an annual Independence Day celebration and other special events. A photograph is shown in Fig. 1. The measurements consisted of three 12.7 mm, Type-1 microphones located down near the field (see diamonds in Fig. 1 and a photograph in Fig. 2) and five teams of students carrying class-1 sound level meters (see Fig. 2). The sound level meters were used to record 1-s, A-weighted equivalent levels on the slow time scale at various positions inside and outside the stadium. The stationary microphones were used with to make audio recordings of the entire games that were then be used to find the *relative* slow, A-weighted measured levels from the sound level meters. The measurements were made over multiple games with the microphones in the same position.

FIGURE 1. Eastward-looking view of Lavell Edwards stadium in Provo, Utah. Shown are diamonds marking the positions of three stationary field microphones.

The teams of students were given sound level meters and logbooks with maps of the surround area and asked to keep detailed records of what was occurring during their measurements: time, location, background noise and significant events, the program material being played over the sound system, any audible crowd noise, etc. This alone resulted in significant learning experiences for the students, as some found out after the first game that they needed to be far more detailed in their note taking so that their measurements could be interpreted by others!

FIGURE 2. Left: Sideline microphone attached to railing and encased in a spherical foam windscreen. Right: A student team with logging Class-1 sound level meter and logbook.

Maps of the surrounding area are displayed in Fig. 3. The stadium is at position 0 of the upper photo. The mountains are to the east of the stadium, which runs north-south. The sound system is mounted at the top of the north end of the stadium and fires south toward the BYU campus, which is mostly at a higher elevation than the stadium. The elevation increase to the south and east of the stadium toward the mountains is seen in the three-dimensional rendering (lower photo of Fig. 3) with the red line that runs between the stadium and a location in the foothills, approximately a 150 m increase in elevation. This foothill location, at a distance of approximately 2.7 km, corresponds approximately to the bottom right corner of the two-dimensional map in the top of Fig. 3, position 5.

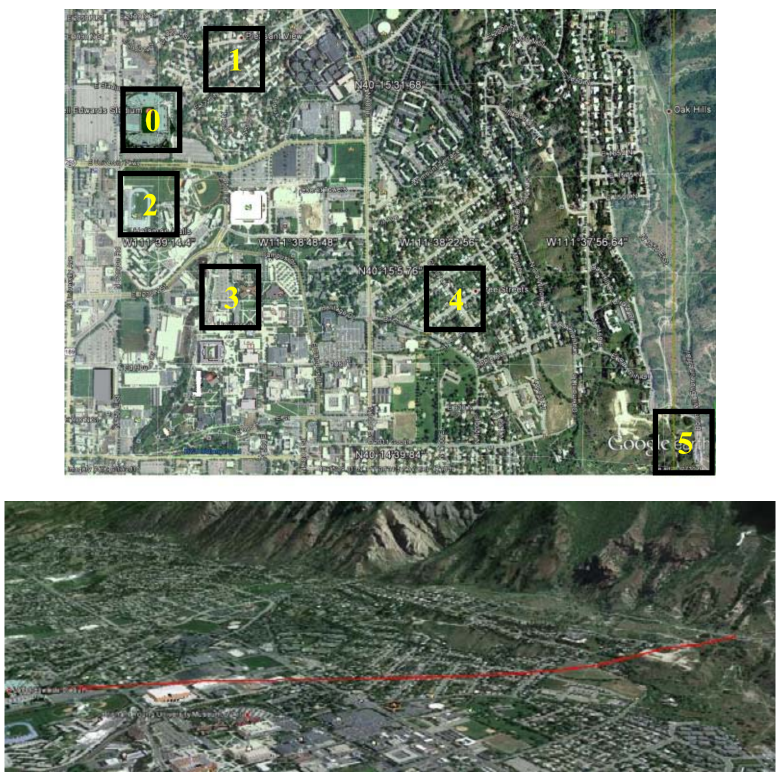

FIGURE 3. Top: Birds-eye view of the relevant measurement area surrounding the stadium. Five measurement locations of significance are denoted. Bottom: Three-dimensional view showing the 150 m elevation change (red line) from the stadium to the foothills at measurement location 5. Images courtesy of Google Earth ®.

As indicated, the data from the stationary microphones were correlated with the portable sound level meter measurements to find the relative sound pressure level at different locations. During football games, the sound engineers try to achieve a nominal sound level of 90 dBA on the sideline, and so levels were calculated relative to that location. The map of compiled relative A-weighted levels is displayed in Fig. 4 over the same area as Fig. 3. Measurement locations are indicated by the blue "x" marks. While measurements were made at many other locations, the ambient levels precluded quantifying the relative level of the sound system. For example, the sound system was clearly audible at higher elevations in the foothills, but not in the neighborhoods below [e.g., at (1200 m, 800 m)]. Thus the use of spline interpolation between the measurement locations suggests erroneously high levels of ~50 dBA in these relatively foliaged neighborhoods. These results are discussed further in context with outdoor sound modeling results in the next section.

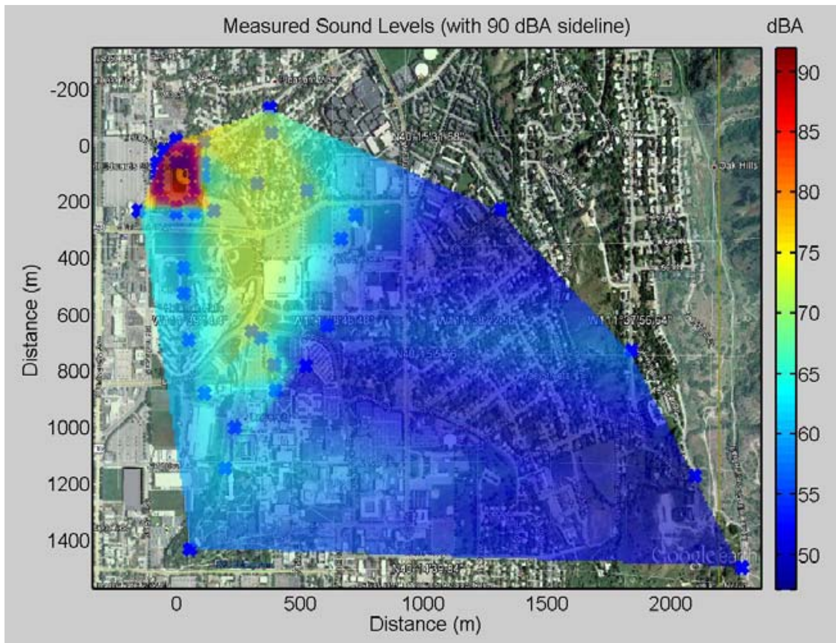

FIGURE 4. Measured sound levels around the stadium with spline interpolation between measurement points (blue "x").

MODELING AND COMPARISONS WITH MEASUREMENTS

To help the students see the predictive capability of models, the results from the measurements were compared with a straightforward outdoor sound propagation model, whose elements are discussed during class. The predicted sound pressure level, relative to L_{ref} on the sideline, is expressed as

$$L_{p,A} = L_{ref} - S - A - D - F - B \quad (1)$$

where the reductions in level due to spherical spreading (*S*), atmospheric absorption (*A*), directivity (*D*), foliage (*F*), and finite thin barrier (*B*) effects are included. The standard equations for atmospheric absorption as a function of ambient pressure, temperature, relative humidity and frequency were used, and nominal frequencies of 500 Hz to 1 kHz were assumed, given the relative importance of those frequencies in the sound system output. Directivity was included as a simple correction to the overall A-weighted level based on measurements made of the sound system by walking around the top of the stadium and correcting to a common distance. Foliage was incorporated empirically with the level correction calculated as in Ref. [7]: $F = 0.01 r_F f^{1/3}$, where r_F is the propagation distance through the foliage and f is frequency. The multiple paths around a thin, finite barrier were also included, with the attenuation from the ith path calculated using Fresnel number, N_i, as $B_i = 5 + 20\log_{10}\left(\sqrt{2\pi N_i}/\tanh\sqrt{2\pi N_i}\right)$.[7]

Example calculations for a number of locations shown in Fig. 3 are considered and compared to measurements. This process helps show how the analysis of the data and the modeling capabilities introduced in this course are reasonably compatible. Atmospheric pressure of 0.9 atm, a temperature of 5° C, and a relative humidity of 30% are assumed, yielding an average absorption loss of 6 dB/km. The source is assumed to be at the top of the north edge of the stadium, at a height of 28 m from the field (position 0 in Fig. 3) and a horizontal range of approximately 110 m. In each example, both the measured and predicted levels, rounded to the nearest decibel, are shown in Table I, along with the important modeling parameters.

Position 1 corresponds to a measurement location along the road running east-west to the north of the stadium, behind the speakers. Relative to the sideline, the measured A-weighted levels were -18 dBA. Geometric spreading, absorption, and directivity were included in the model. In terms of A-weighted level, the source was not found to be highly directional, but there is a reduction in level to the very side of the speaker system. Thus, for measurement location 1, D = 5 dBA was used based on the measurements along the top of the stadium. This yields a prediction of -19 dBA, a loss of only 1 dBA more than measured.

The students' typical reactions to a calculation like that presented for position 1 is that of skepticism – it's easy to guess at the answer once. The other measurement locations are chosen to show a variety of other effects, with good agreement in each case. Position 2 is immediately south of the stadium, still in the shadow zone of the barrier created by the south stands. For this example, the students were asked to create a thin barrier used to represent the south stands. Using approximate dimensions obtained from the three-dimensional building in Google Earth®, they created a barrier that was the same height as the stands but represents the average length and was located at the average distance from the source. This also yielded a prediction that is 1 dBA different than the measurement. The map in Fig. 4 was used to discuss how there is a large range south of the stadium that has relatively constant level; the students quickly realized that this is caused by the differing contributions of geometric spreading and the barrier as the distance increases.

Position 3 is an interesting case where the barrier is not included because of the gap in between the east and south stands. The resulting calculation overpredicted the measured level by 3 dBA. However, the path between the stadium and the measurement position is not completely unobstructed and the students were encouraged to discuss the limitations of the model. Position 4 is in a region where the sound system was completely inaudible because of the ~40 dBA ambient levels. However, reasonable inclusion of the effects of foliage and buildings in these neighborhoods suggests drops in level of around 100 dBA, so the inability to hear the sound system is quite explainable.

Finally, the mountains to the east represent an excellent opportunity to obtain relatively free-field measurements of the sound system at longer ranges and higher elevations. One team of students drove into the foothills southeast of the stadium and were able to clearly hear the sound system. At position 5, 2.7 km from the stadium, their measurements indicated a 40 dBA drop in level relative to the sideline. Inclusion of absorption and spreading resulted in a predicted 42 dBA reduction. This facilitated a discussion of whether using the 500 Hz or the 1 kHz results is best justified, because over this distance, the difference is several decibels. Again, the limitation of the model, which is based solely on overall level, A-weighted levels was discussed.

TABLE 1. Comparison between measured and modeled levels for the six locations shown in Fig. 3. Included are some brief comments about salient modeling points. See the text for further details.

Location	Measured rel. sideline (dBA)	0.5-1 kHz avg. prediction (dBA)	Model Comments
0	0	0	Reference location
1	-18	-19	D = -5 dB, r = 440 m
2	-29	-28	r = 440 m, *barrier distance 200 m, barrier length 110 m, barrier height 28 m.*
3	-28	-25	*No barrier*, r = 980 m
4	< -50	-105	r_F=350 m, r = 1.7 km
5	-40	-42	r = 2.7 km

SUMMARY

The students uniformly express appreciation for the opportunity to put in practice what they are learning in the classroom. In addition, they understand better what it is like to make a real measurement, where calibrations, testing of sound level meter battery life and data capacity, and logging of measurement details are not only helpful but are essential. From the faculty viewpoint, the measured data provide an exciting context to explore the capabilities and limitations of a simple outdoor sound predictive tool. However, there is a lot of work in setting up the measurements and getting the data into a format the students can utilize. If, in the future, we put more burden on the students to analyze the data quickly, there are other things in the class that we will need to cut. However, requesting additional teaching assistant support could help strike an appropriate balance. Ultimately, although this is an activity that is not without cost, student engagement and enthusiasm are relatively high. Consequently, we plan on seeking out additional opportunities for the students in the future.

ACKNOWLEDGMENTS

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