Predicting Convergence Zone Propagation in Environmental Noise Measurements

Paper 0343

24 – Sound Propagation in the Atmosphere

R. L. Bronsdon [1] and H. Forschner [2]

[1] Walt Disney Imagineering, 1401 Flower Street, Glendale, CA 91221, USA
[2] Navcon Engineering Network, 701 W. Las Palmas Drive, Fullerton, CA 92835, USA

Introduction

Most measurements made on environmental noise sources are done whenever it is convenient without any real consideration to the effects of environmental factors such as wind and temperature gradients. Predictions are typically done assuming that the atmospheric conditions are stable and benign. When the predictions and test results are compared and do not match, a generalization is given. “It must have been caused by some type of atmospheric condition.” A computational Gaussian Beam program that accounts for the effects of wind and temperature inversions was presented at Inter-noise 98 in New Zealand and is now currently a part of the SoundPLAN program for evaluating environmental noise. That program is designed primarily to deal with temperature inversions and wind that is blowing from the source to the receiver but it does provide insight into upwind propagation.

This paper deals with upwind propagation of sound in temperature inversion conditions. When the proper wind and temperature profiles exist it is possible to form either an elevated duct, where sound will propagate at 3dB/DD, or perhaps even a convergence zone where the propagating sound will not be attenuated any appreciable amount. We experience these types of propagation when we hear familiar sounds that seem to have moved closer. A good example would be the sound of a highway or train at a great distance, which suddenly seems to be running right through the back yard. A simplified calculation based on Gaussian Beams allows the investigation of conditions under which these types of phenomenon could possibly occur. More sophisticated analysis techniques also show how convergence zone propagation can impact noise measurements made out of doors.

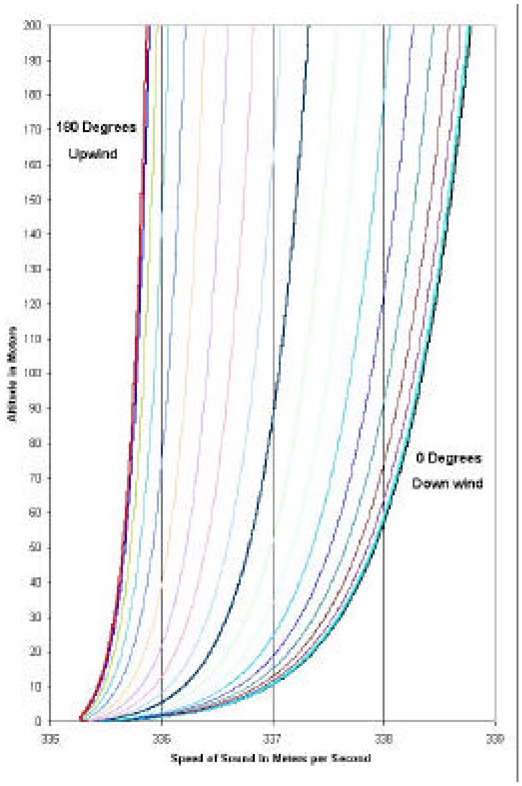

Figure 1. Sound Speed Profiles that show a knee in

Convergence Zone Propagation

Convergence zones can form when knees form in the sound speed profile. These knees can be a characteristic of the wind profile itself, caused by stratified wind currents, or they can be

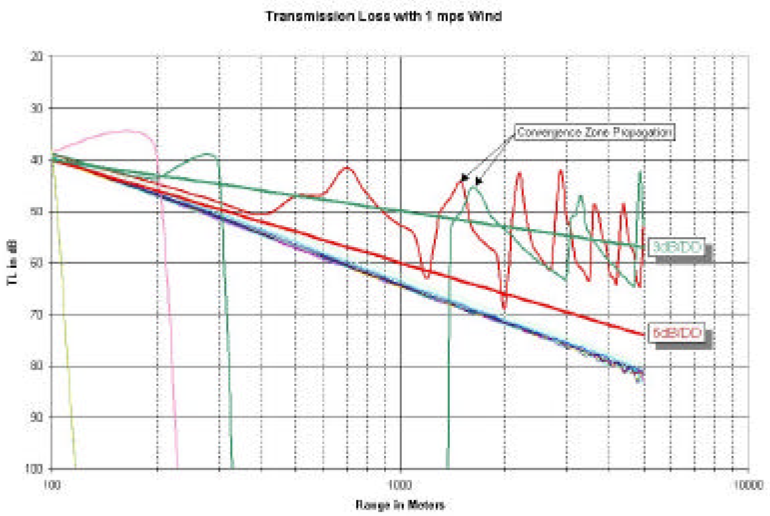

Figure 2. Predicted convergence zone sound propagation upwind.

caused by an interaction between the temperature inversion profile and the wind profile. The Gaussian Beam program that is used here simplifies the wind and temperature profiles, through the use of Similarity Theory, into exponential curves. These data are then used to calculate the speed of sound profiles as shown in Figure 1. The temperature is not a vector but the wind is so the sound speed must be evaluated in increments around the source. A sound speed profile for each increment is then used to calculate the beam paths in a step-wise fashion. While this is not a true sound field calculation like a Parabolic Equation (PE), it is much more sophisticated than a simple ray tracing in that it is done based on the actual sound speed profile that exists for each step of the calculation along each beam. The final determination of transmission loss is based on the summed contributions from all of the beams. This transmission loss can include convergence zone propagation in regions where the wind and temperature profiles are exerting conflicting controls over the path.

Figure 2 shows that convergence zones can be predicted when the proper combinations of wind and temperature profiles exist. The concentration of energy can be seen to exceed even 3dB/DD at some positions. The predictions for the downwind propagating sound can be seen to be dropping off at a rate that is greater than 6 dB/DD. This is caused by the curved nature of the propagation paths. This curvature distributes the energy in each beam over a greater area and results in a lower received level.

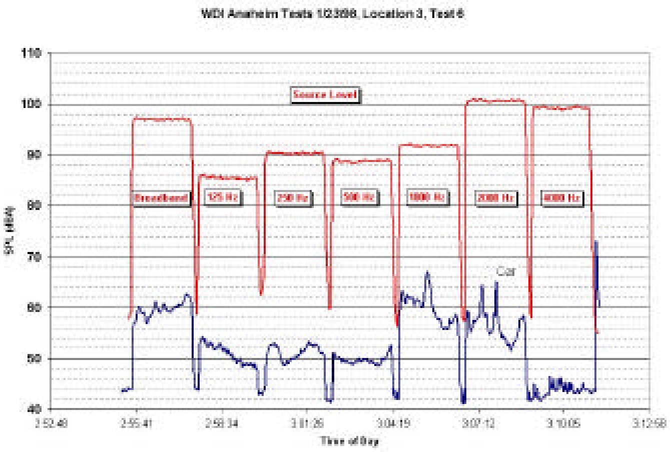

Figure 3. Variation of level during testing

Convergence zone propagation upwind can be a relatively stable condition. A convergence zone that is created by a steady wind and a temperature inversion will persist for the length of time that those conditions exist. Where the wind and temperature profiles approximate the conditions described by Similarity Theory, there can be no convergence zone propagation down wind as both the wind and the temperature are tending to bend the sound back towards the ground. Wind profiles are, unfortunately, never very steady and small scale fluctuations in wind speed can conspire to create convergence zone propagation even in down wind conditions.

It would be reasonable to ask if one would expect to see the effects of these propagation anomalies in normal measurements. Testing in the field, using very large speaker arrays and band limited pink noise as the source material, reveal that short-term fluctuations in received level are clearly occurring. These fluctuations can only be explained through some type of energy concentrating mechanism in the sound field. The received levels shown in Figure 3 graphically demonstrate strong, short term fluctuations which were clearly caused by changes that could only have occurred in the propagating medium. The only possible change in the propagating medium would be the wind speed. The operator stationed at the receiving position noted the short, rapid, increases in received level during the test. These variations represent fluctuations of over ten dBA in a 30-second period. In fact, if you look at the transmission loss over the four minutes of the two tests at 1000 and 2000 Hz, it varies from a minimum of 25 dBA to a maximum of 49 dBA.

This immense difference is the basis for making long term averages on noise levels that are measured out of doors. Our knowledge of the actual atmospheric conditions, along with our simplistic propagation models tends to force us to ignore these short-term fluctuations. As propagation models become more accurate reflections of true sound field development, we get closer and closer to being able to predict the impact that noise sources will have on the surrounding community. The normal predictions, based on average performance, may well point to a successful project but the complaints are likely to come from the short-term exceedences that are caused by the difficult atmospheric conditions.

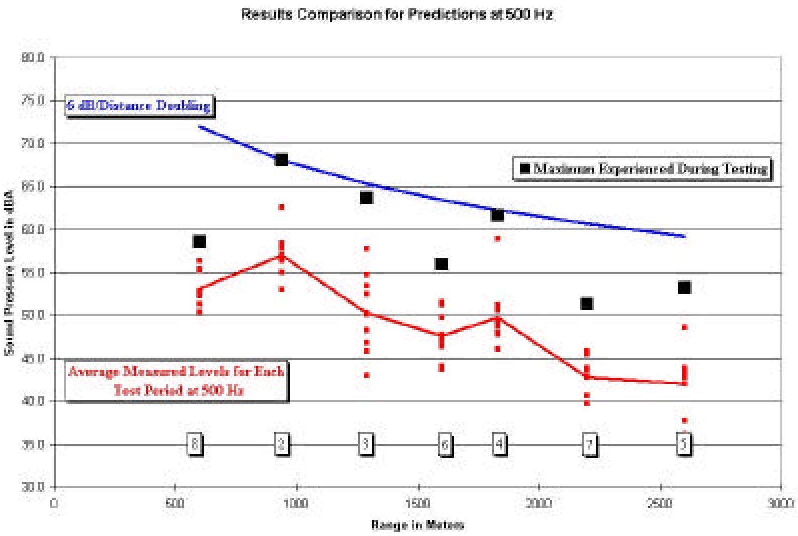

Figure 4. Comparison of average received levels to maximum received level

Average testing results are shown in Figure 4. Here average performance, as indicated by the smaller red squares and the red line, are compared to the highest levels measured during the test, the larger black squares. It is clear that while there is some variation at each site, it is difficult to see how the maximums could come so close to the fundamental spreading loss term. How can air absorption, barrier insertion loss, ground effect, and directionality all disappear for a short period of time if not through some mechanism that concentrates the energy in the sound field.

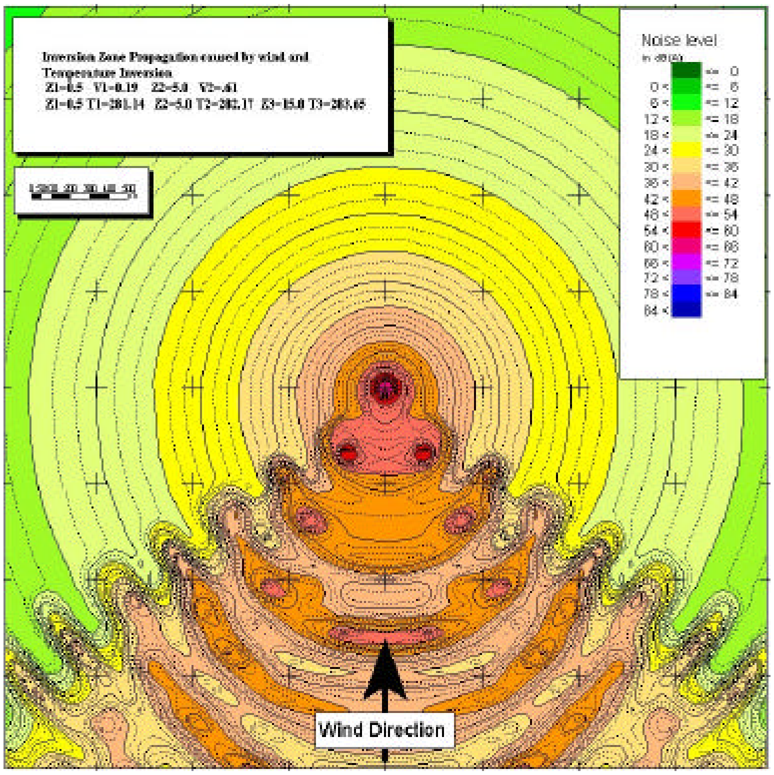

Figure 5. Convergence Zone Prediction due to Wind and Temperature Gradients

Figure 5 shows a SoundPLAN generated Gaussian beam prediction of convergence zone propagation resulting from a combination of wind and temperature affects. The conditions for the simulation are based on measured metrology at Edward's Air Force Base. An omni directional source is placed in a large open area with a temperature inversion and a gentle wind from the South.

The contour map in Figure 5 shows that in the upwind direction the predicted noise levels are louder than in the down wind direction. The combination of wind gradient and temperature inversion have created an acoustical duct, where the sound decay in the upwind direction was close to a 3 dB/DD curve. In some conversion zones the predicted levels even exceeded the 3 dB/DD level.

Conclusion

Convergence zone propagation has been affecting noise measurements since man invented the microphone and has been a part of the human experience for a far greater amount of time. We experience these types of propagation anomalies when we hear a known source as apparently moving closer, or farther away. History has recorded great battles that have turned on the sounds of troop movements being directed away from the enemy positions.

It would be unreasonable to assume that these types of conditions are uncommon but our models are just now becoming sophisticated enough to predict this type of propagation. Even as our models improve, we find that the data needed to make the correct predictions is not available. Similarity theory might be close enough for predictions of average performance, but predictions of short-term fluctuations will require an instantaneous knowledge of the dynamic flow field that the sound propagated through. It does not look like this kind of information is likely to come from fixed point sensors placed at any location within the propagating medium as they can only tell us what they see at that location. This type of data is more likely to come from emerging technologies in Doppler radar or LIDAR, which are currently being used to investigate large flow fields around tornadoes and hurricanes.