ENHANCEMENT OF FAR-FIELD SOUND LEVELS BY REFRACTIVE FOCUSING

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ABSTRACT

The enhancement of sound pressure levels resulting from refractive focusing has been calculated for meteorological conditions representative of those observed at the MOD-1 site near Boone, N.C. The results show that 10 to 20dB enhancements can occur over ranges of several hundred meters. Localized enhancements in excess of 20dB can occur but will probably be of limited duration as a consequence of normal temporally varying meteorological conditions.

INTRODUCTION

Refractive propagation of sound which produces zones of enhanced and diminished audibility at varying distances from the source has been of intermittant interest since the turn of the century. In fact prior to rocket soundings, analysis of the so-called anomalous propagation provided Whipple (1923) and others with one of few available means for studies of upper atmosphere temperature profiles.

Although there have been a number of studies of refractive propagation resulting from wind and temperature gradients in the atmosphere's planetary boundary layer (the lowermost one to two km), the results of these studies ought now to be reviewed in the light of our recently, vastly, improved knowledge of meteorological boundary layer structure and processes. The lack of adequate supporting meteorological measurements, for example, greatly diminishes the value of the otherwise careful 13.5 Hz measurements and analysis by Chung (1972). In retrospect the author and his colleagues (Greenfield et. al., 1974) should have included evaluation of the contribution by wind shear in elevated temperature inversions to their analysis of 200 Hz refractive propagation. Artillery sound ranging errors have also been extensively evaluated (see e.g. Lee, 1969). However, results from case studies appear to be either lacking or not readily available.

About one year ago, the meteorological acoustics group at Penn State assisted SERI with field measurements and began analysis of the noise disturbances associated with the MOD-1 WECS situated at Boone, N.C. Results of the preliminary studies are available in the technical report by Thomson (1980) which is currently in press at SERI. These studies clearly established that refractive focusing of the sound by wind shear in the vicinity of the MOD-1 WECS could have contributed to unacceptably high noise levels at several of the locations from which complaints had been registered. The results of this paper include recently completed estimates of the enhanced sound pressure level (relative to spherical spreading) of a caustic, the domain of which has been set to conform to typical dimensions of a residential unit.

MODELING TECHNIQUE

The motion of the acoustic wave front $s(\vec{x},t)$ is described by the Eikonal equation

$$2\nabla\theta_n\cdot\nabla s + \left\{ \nabla^2 s - \frac{1}{c^2}\,\frac{\partial^2 s}{\partial t^2} \right\} \theta_o = 0$$

where θ_n are the series coefficients in the expansion of the potential velocity, c is the phase velocity and θ_o the initial angle of a specified ray.

The Eikonal equation is numerically solved for nonhomogeneous, anisotropic media, i.e. for wind speed and temperature varying (externally specified) with height. A unique aspect of the computer program is the inclusion of the tracking of rays which have undergone reflection at a complex terrain (non-horizontal slope) surface. Figure one illustrates such a ray trace including focusing near one of the MOD-1 impacted homes.

The exact location of a focus point, caustic, is critically dependent upon meteorological conditions at the mountain site. Variations in the time scale of a few minutes in the vertical wind speed profile near the mountain top can easily displace a caustic several 10's or even hundreds of meters. To evaluate the temporal variability factor we hope shortly to be able to produce "tracks" of caustic positions using processed micrometeorological data from the Univ. of Virginia and Pacific Northwest Labs tethersonde flights. In order to evaluate the sound pressure level at an arbitrary receiver location, we use an eigenray routine which searches a range of angles and employs a bisection method to zero in on the initial angles of rays at the source. Corrections are made for spherical spreading and both ground reflection and atmospheric absorption losses. In their present form the eigenray programs are not yet able to be used for predicting actual sound pressure levels for complex terrain locations.[1] We recognize, however, the substantial community interest in knowing the approximate magnitude of enhanced sound levels resulting

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[1] The necessary modifications are scheduled as a part of a larger research effort to be performed by us for SERI

from refractive focusing and, therefore used the currently operating ray trace and eigenray routines for homogeneous terrain to produce figures 2 and 3.

RESULTS

The environmental vertical sound velocity profile on the right of Fig. 2 corresponds to a nocturnal situation characterized by a weak thermal inversion capped by an elevated (mountain top) region of strong wind shear. At higher altitudes we assume a weak temperature lapse and negligible wind shear. Figure 3 is a plot of the noise enhancement (above spherical spreading) as a function of distance from the source. The principal curve corresponds to 10m source and receiver heights, respectively. For comparative purposes a few points are included for a 30m source height. As indicated earlier the receiver domain was set in both cases to be 20m in horizontal extent. Noise level enhancements of order of 10dB are thus easily realized and 10 to 20dB and even higher can occur.

In theory, the sound pressure level at an incremental caustic can be infinite. The actual spatial and temporal properties of caustics resulting from atmospheric focusing have not, to our knowledge, yet been examined. Consequently, our future studies will include detailed analysis of the characteristics of points such as the indicated 27dB enhancement present at 1.25 km on Fig. 3.

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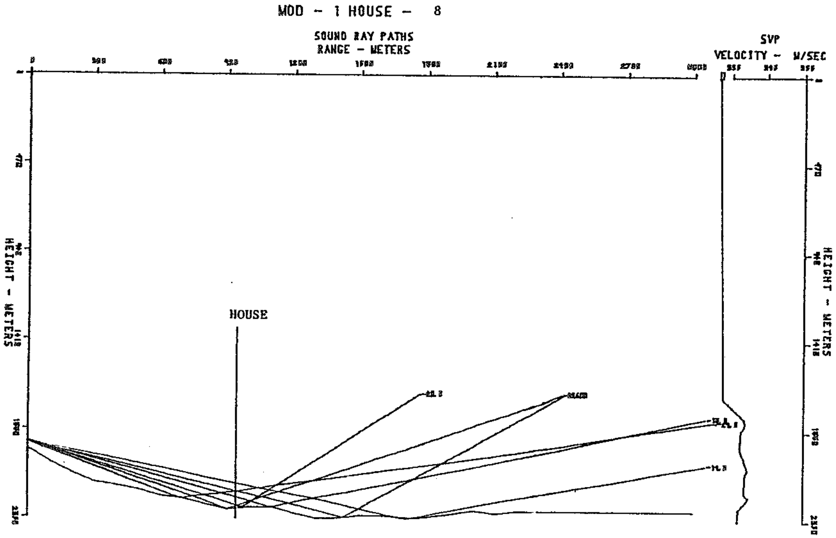

Fig. 1. "Crosswind" Ray Trace (-24 to -16), 105° Terrain and Bearing, Univ. of Virginia Profile 8.

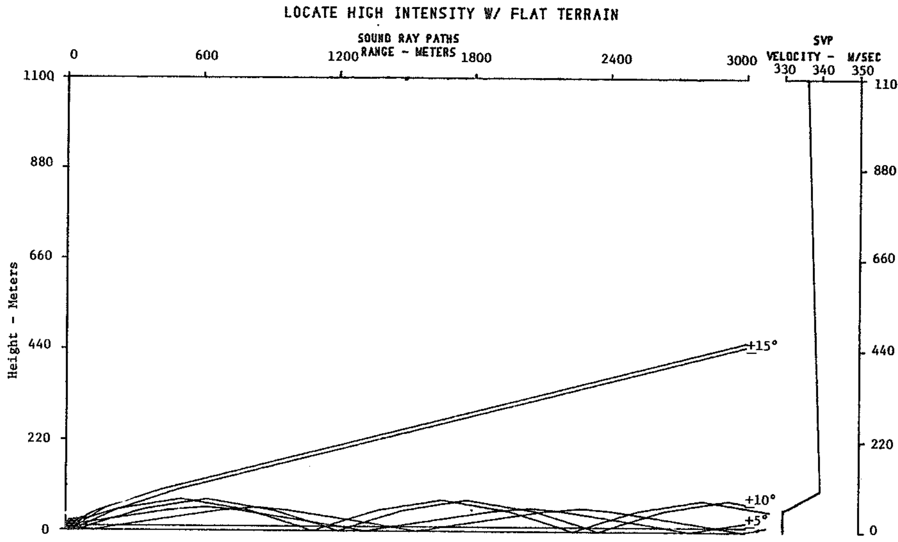

Fig. 2. Ray trace for following sound pressure level enhancement case.

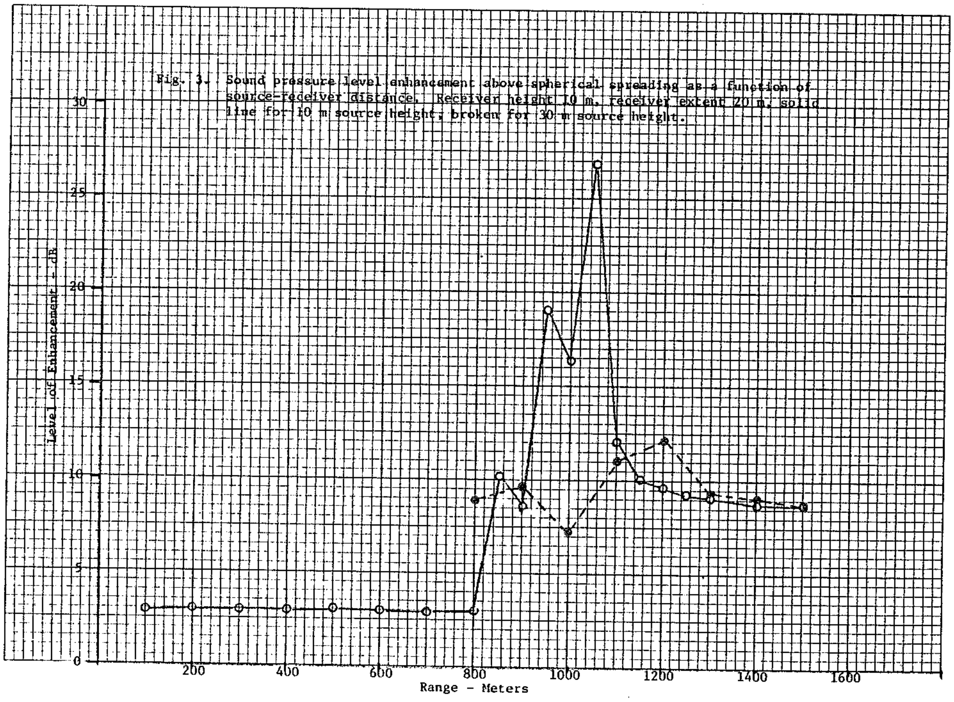

Fig. 3. Sound pressure level enhancement above spherical spreading as a function of source-receiver distance. Receiver height 10 m, receiver extent 20 m, solid line for 10 m source height, broken for 30 m source height.

QUESTIONS AND ANSWERS

D.W. Thomson

From: S. Quraeshi

Q: What, in your opinion, would be the effect of location of HAWTG on a hill or in a valley (effect on noise, propagation, amplification, distance)?

A: *Flow convergence near a hilltop will tend to increase downwind sound levels. Flow divergence downwind of a valley or channel location will tend to reduce downwind noise levels.*

From: Anonymous

Q: What was relative enhancement of upwind versus downwind?

A: *Upwind: 3-7 dB*
Downwind: 10-20 dB

From: Anonymous

Q: Is the primary mechanism responsible for refractive focusing the wind shear or temperature (density) gradient?

A: *It is the wind shear by about an order of magnitude.*

From: J.R. Connell

Q: What effect would you expect for vertical profiles of wind (at a mountain top) which have reduced on negative shear?

A: *Reduced downwind noise levels or even refraction of the sound upward if the negative shear profile is sufficiently large to overcome the temperature gradient (inversion) contribution to the vertical sound velocity profile. However, for isolated peaks the work of Hunt at Cambridge and Mason and Sykes of the English Met Office indicate that 3-dimensional flows will enhance downwind focusing.*

From: G.P. Tennyson

Q: If we can provide fairly good wind profiles, directions, velocities, etc., can you forecast noise focusing so as to evaluate a site ahead of time?

A: *Yes, but as far as I know, the wind and temperature profiles which are needed for acoustic propagation analysis are not currently made in site evaluation studies.*

From: G. Greene

Q: Are you suggesting the problem is totally due to refraction or just enhanced?

A: *The problem is only aggravated by refraction. The only solution is suppression of the noise at the source. Even a "relatively quiet" machine may produce occasionally annoying levels due to refractive focusing.*

From: F.W. Perkins

Q: What climate types will have most and least focusing? Hot and dry versus cold and wet, for example.

A: *Climate in the sense of say, desert versus coastal fog conditions, is not the principal factor. What is important is local terrain and the diurnal structure and evolution of the atmosphere's planetary boundary layer. Generally, the worst case conditions will be associated with complex terrain where strong shear (wind) is generated by the underlying surface and nighttime conditions where the atmosphere tends to be dynamically stable and hence, acres of large wind shear can exist in the lowest 100 to 500 m height.*