EFFECT OF THE GROUND SURFACE AND METEOROLOGICAL CONDITIONS ON THE ACTIVE CONTROL OF A MONOPOLE NOISE SOURCE

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1. INTRODUCTION

Until recently, most studies of active noise control (ANC) have focussed on noise reduction in free- or half-space or in an enclosure; moreover, the medium is assumed to be non-refracting. In order to study the effectiveness of an ANC system in an outdoor environment, it is essential to include meteorological and realistic ground effects. In this research, the Green's function parabolic equation method (GFPE) developed by Gilbert and Di [1] was used to predict the sound field of a monopole primary source and a single monopole control source at 80Hz in one dimension for several atmospheric conditions. The results indicate the feasibility of using an active system to control the noise radiated from a Dash-8 propeller aircraft during engine run-up tests; 80Hz was chosen because it is the blade-passing frequency of the Dash-8.

2. ATMOSPHERIC AND GROUND CONDITIONS

In the prediction of long-range outdoor sound propagation, the effects of a refractive atmosphere must be taken into account. Refraction of sound waves is caused by temperature and wind-speed gradients. Temperature gradients can be described as a lapse or an inversion. During a temperature lapse, there is often a decrease of 5°C in the first meter above the ground and a further decrease of 3 to 5°C in the next 100m. A weak temperature inversion can be represented as an increase of 0.9°C/100m, a medium inversion as 1.8°C/100m and a strong inversion as 3.6°C/100m [2].

The variation in the wind speed is greatest near the ground surface, and decreases with increasing height. A realistic profile for the effective sound speed at height z is $c_{\text{eff}}(z) = c_0 + b\ln(z/z_0 + 1)$, where c_0 is the sound speed at the ground, z_0 is the roughness length of the ground surface in m, and b is a parameter describing the refraction in m/s [3]. For the results shown here, $c_{\text{eff}}(z)$ was calculated using b = 1 m/s for downwind, b = -1m/s for upwind, $z_0 = 10^{-4}$m for hard ground, and $z_0 = 10^{-2}$m for soft ground.

Single-channel ANC predictions were performed for hard ground and soft ground (Z = 14.65+13.63i), for weak, medium and strong temperature inversion conditions in the presence and absence of a downwind, as well as for temperature lapse conditions in the presence and absence of an upwind.

3. RESULTS

The GFPE code was modified to include a single active control channel using equations described by Guo and Pan [4]. The model was validated for single-channel ANC predictions by comparing the results obtained using the GFPE model with Guo's and Pan's model for a non-refractive atmosphere above a reflective plane. Predictions were done up to a horiztonal distance of 10km, using source and receiver heights of 4.5m. For all of the predictions, the control source and error sensor were positioned in a line at the height of the primary source. The control source was placed at a distance of 30m from the primary source, and the error sensor was placed 30m from the control source.

The results for temperature inversion and lapse conditions above a reflective ground surface are shown in Fig. 1. In the case of no refraction, about 13dB of attenuation was achieved in the far field. The temperature inversion caused fluctuations in the attenuation of $\pm$ 2 to 3dB. About 10dB of attenuation was achieved on average under weak and strong inversion conditions. Under medium version conditions, about 13dB of attenuation was obtained on average. In these cases there were significant spatial variations. The temperature lapse did not cause fluctuations in the attenuation, but the ANC system was less effective for this case overall, achieving only 5dB of attenuation.

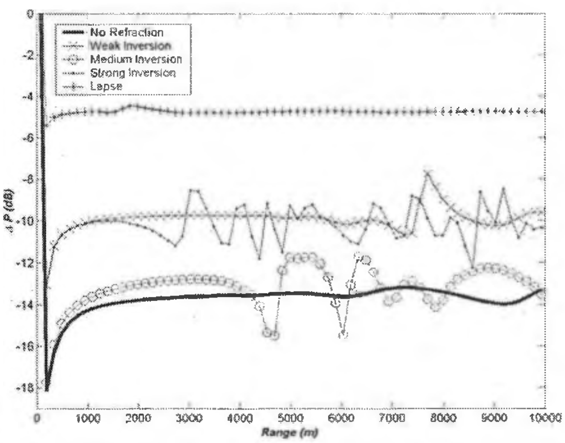

Fig. 1. ANC results for a monopole at 80Hz in the presence of temperature gradients above reflective ground.

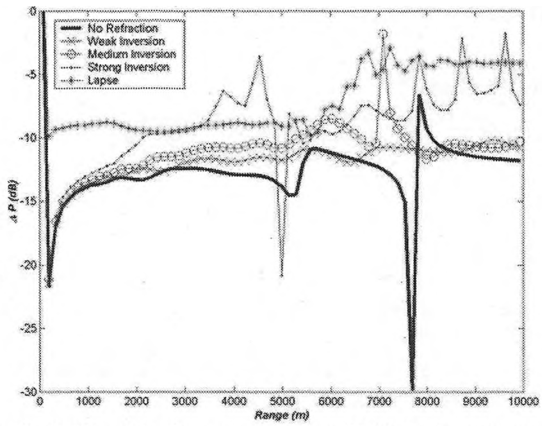

Fig. 2. ANC results for a monopole at 80Hz in the presence of temperature gradients above soft ground.

For temperature inversion and lapse conditions above soft ground, the results are shown in Fig. 2. The attenuation for a non-refractive atmosphere is also shown, to show the effect that the soft ground has on the control results (compare with Fig. 1). About 11 to 12dB of attenuation was achieved over the entire range, except at 7.7km where there was a sharp dip. Similar attenuation was obtained under weak inversion conditions. With the medium inversion, 11 to 12dB of attenuation was obtained on average, but a sharp peak (up to -2dB) occured at 7km. Under strong inversion conditions, there were large fluctuations in the attenuation in the far field, with the average attenuation being about 5dB. Under temperature lapse conditions, about 10dB of attenuation was achieved up to 5km; beyond the 5km point, only about 5dB was obtained.

Fig. 3 shows the results for temperature inversion with downwind conditions, as well as for temperature lapse with upwind conditions, in the presence of a reflective ground. The results for the different degrees of temperature inversion are almost identical, showing 4dB of attenuation along the entire range. The control system is ineffective under temperature lapse conditions in the presence of an upwind; the sound field increased by 2 to 7dB.

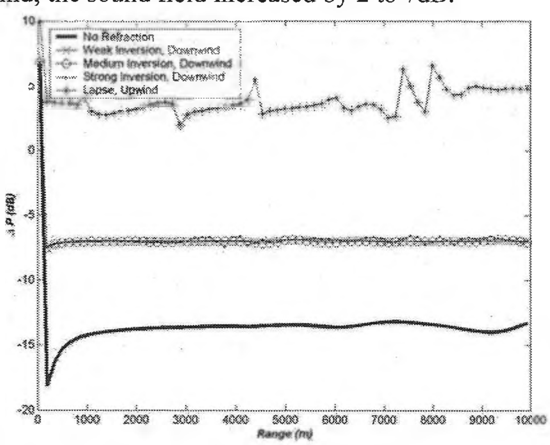

Fig. 3. ANC results for a monopole at 80Hz in the presence of temperature and wind-speed gradients above reflective ground.

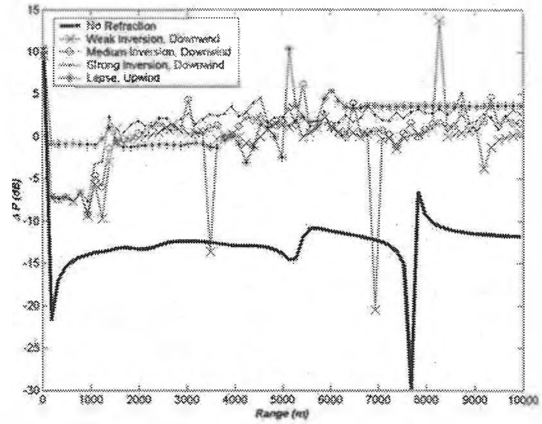

Fig. 4. ANC results for a monopole at 80Hz in the presence of temperature and wind-speed gradients above soft ground.

Fig. 4 shows the results for the most complex conditions, combining temperature and wind-speed gradients above soft ground. The control system did not achieve any attenuation at large distances. The weak inversion with downwind, and lapse with upwind, caused a few peaks and dips in the attenuation, while the field was relatively constant over the range for the medium and strong inversions with downwind conditions.

4. DISCUSSION

Clearly, atmospheric refraction and soft ground have a significant effect on the performance of a single-channel ANC system. It is most difficult to achieve attenuation under temperature lapse conditions, especially in the presence of an upwind. However, under such conditions the noise levels near the ground have already been signicantly attenuated due to the upward refraction of sound waves. It is thus more important to concentrate on attenuating the noise under temperature inversion and downwind conditions. Using single-channel control over soft ground, a quiet zone (10dB of attenuation or more) was achieved under weak temperature inversion conditions, but the control system was less effective for stronger temperature inversions. Future work should investigate multi-channels ANC system.

1. K. E. Gilbert and X. Di. A fast Green's function method for one-way propagation in the atmosphere. J. Acoust. Soc. Am. **94**(4), 1993.
2. T. F. W. Embleton. Tutorial on sound propagation outdoors. J. Acoust. Soc. Am. **100**(1), 1996.
3. E. M. Salomons. Computational atmospheric acoustics. Kluwer Academic Publishers, 2001.
4. J. Guo and J. Pan. Effects of reflective ground on the actively created quiet zones. J. Acoust. Soc. Am. **103**(2), 1998.

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