Proceedings of 20th International Congress on Acoustics, ICA 2010

23-27 August 2010, Sydney, Australia

Helicopter Noise Propagation Characteristics in the Refracting Atmospheric Conditions

Eunkuk Son (1), Seungmin Lee (1) and Soogab Lee (2)

(1) Department of Mechanical and Aerospace Engineering, Seoul National University, Republic of Korea
(2) The Institute of Advanced Aerospace Technology, Department of Mechanical and Aerospace Engineering, Seoul National University, Republic of Korea

PACS: 43.28.Fp, 43.28.Hr , 43.50.Lj

ABSTRACT

Noise prediction during a flight is one of the important research themes in a helicopter as it radiates a higher noise level toward a ground. There are several attempts to predict the noise level with various attenuation effects. However, since ray's path and magnitude radiating from the helicopter are changed due to a temperature profile and a wind speed profile in a refracting atmosphere, the propagation model has to contain not just air absorption but also effects of the atmospheric stability. In this paper, effective sound speed profiles are calculated according to Monin-Obukhov length, an atmospheric stability, and it is used for the prediction of ray path. There are also reflected wave and diffracted wave considerations in the model. Noise sources from the helicopter are built by HeliPA code developed in AeroAcoustics and Noise Control Laboratory (AANCL). The noise sources from HeliPA are applied to the propagation model as input data and EPNdB can be obtained from the predicted SPL results. Moreover, noise levels near a practical airport region are simulated with GIS terrain profile.

INTRODUCTION

Endeavors reducing helicopter noise have been conducted over the past several decades. There are not only noise source's points of view, noise mechanism of a helicopter, but receiver's points of view, a noise prediction near helicopter flight paths. Recently, a research on the noise prediction over the receiver region becomes very important role of developing the helicopter and land use planning. These studies assess the noise effects from a helicopter to inhabitants and then ensure convenient lives from the noise. To acheive these goals, an issue on a method for a prediction of sound pressure level from a helicopter during a flight will be treated as an important research themes. The method has to be contained a model with atmospheric conditions and various propagation characteristics in a variety of terrains. A well known propgation tool for the helicopter is Rotorcraft Noise Model (RNM) developed by NASA-Langley research center. [1] Noise database in this model has been developed by the full scale flight test. It is very well constructed with huge costs and time. However, we have developed a helicopter environmental noise prediction model by the numerical analysis, both the noise database and the propagation model; it could reduce the huge burden. Propagation model based on ray theory is designed to consider atmospheric effects and terrain effects. Ground reflection is calculated with an impedance value and diffraction effect is also considered. The atmospheric model contains an air absorption effect and a refracted wave effect. We use an effective sound speed profile for fine results of ray paths. The effective sound speed is calculated by Monin-Obukhov similarity relation giving a practical sound speed distribution.

The noise source is analyzed by HeliPA developed by AANCL. Noise database of the helicopter is used as an input for the propagation model. For various flight paths and conditions, an acoustic sphere, a noise database, is constructed with a function of the angle of a tip path plane and an advance ratio. This acoustic sphere reflects far field sound characteristics of the helicopter. With this database, a prediction of sound propagation from the helicopter during a flight is conducted with both a flat terrain and a terrain shape using GIS data.

PROPGATION MODEL

Ray theory is a most favorable tool for the prediction in the outdoor sound propagation. Its applications to the complicated terrains or the various atmospheric conditions are quite simple and straightforward. The method could be applied to moving sources. The governing equation on ray theory is Eikonal equation whose solution gives the information on ray trajectory. Eikonal equation derived from a wave equation is following.

$$\left|\nabla^2 \tau\right| = \frac{1}{c^2} \qquad (1)$$

Ray path is obtained from equation (1) using by 4th order Runge-Kutta formula. Finding an eigen-ray, root finding methods are conducted such as Newton-Raphson method or bi-section method.

SPL calculation at receiver's region is combined with the effects of the air absorption and the reflected wave and the diffracted wave using the eigen-ray. The sound pressure level at the receiver is eventually following. [2]

$$L_R = L_{P_{free}} + \Delta L_a + \Delta L_{ref} + \Delta L_{diff} \quad (2)$$

L_R is the SPL at receiver and $L_{P_{free}}$ represents source's SPL at free field, an acoustic source panel in this paper. ΔL_{ref} is an effect of the relfected wave and it is sometimes called a relative sound pressure level. To obtain a relative sound pressure level, it requires four parameters. R_1, R_2, Z, k, those are distance from a source to a receiver with a direct ray path and a reflected ray path, a complex impedance, and a complex wave number, respectively. From these values, we can calculate a spherical reflection coefficient with image source distributions then also obtain the relative sound pressure level. Attenborough's impedance model is used. ΔL_a is an air absorption level and we use ISO 9613-2 model. ΔL_{diff} is an attenuation level by a barrier. Salomons's diffraction model is applied for the calculation of the attenuation level. [3]

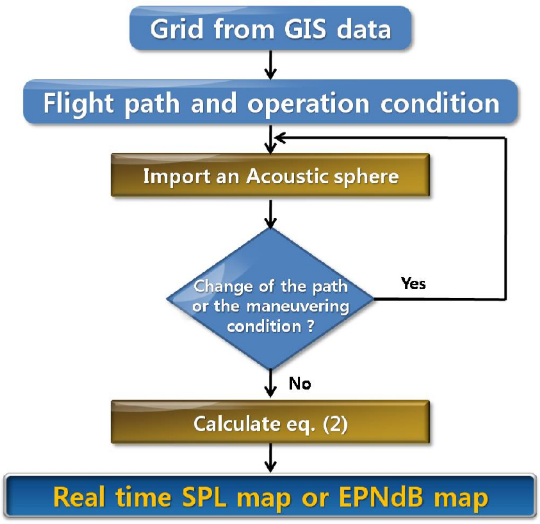

Figure 1. Schematic diagram of a process on the model

The figure 1 is a schematic of the process on the helicopter noise propagation model. Propagation model needs input data, information on the receiver's grid and the flight path and the operation condition. Once the grid system is determined, it remains unchanged. However, the acoustic sphere depending on the condition of flight paths and operation states is changed. The acoustic sphere is instantly updated as a relevant input condition. Finally, real time SPL contour and EPNdB map can be obtained.

REFRACTING ATMOSPHERE

In a practical atmospheric condition, a sound speed is not a constant with a height due to a temperature gradient and wind speed variations. Both the temperature profile and the wind speed profile are a function of x, y, z. However, both profiles are considered as only a function of z, a height, because the variation on x, y direction is generally much less than z direction. Prediction of the sound speed with the height and its application are an effective method. To predict the sound speed in an arbitrary position, the temperature profile and the wind speed variations are considered with an atmospheric stability.

$$c_{eff}(z) = c_0(z) + u(z) \quad (3)$$

Equation (3) is a description of an effective sound speed with the function of a height. $c_0(z)$ is the sound speed calculated by a temperature and $u(z)$ is the wind speed. The both values are simultaneously determined.

The atmospheric stability is mainly divided into three states, an unstable atmosphere, a neutral atmosphere, and a stable atmosphere. If a turbulent part in the z-direction, w', has a positive value in the daytime, a turbulent part of a temperature θ' has a positive value because the potential temperature of the air moving from the bottom is higher than the surrounding's. In this case, an atmosphere is called a stable. Opposite case is an unstable atmosphere. $w'\theta'$ is a crucial role for the determination of whether the atmosphere is stable or unstable. From Monin-Obukhov similarity relation, the temperatures and the wind speed profiles can be simply calculated. Its application gives more elaborate prediction on the results of ray paths.

Both profiles can be achieved following the two equations.

$$\bar{u}(z) = \frac{u_*}{\kappa}\left[\ln\frac{z}{z_0} - \Psi_w\right] \quad (3)$$

$$\bar{\theta}(z) = \theta_0 + \frac{\theta_*}{\kappa}\left[\ln\frac{z}{z_0} - \Psi_t\right] \quad (4)$$

$\bar{u}(z)$ and $\bar{\theta}(z)$ are the mean wind speed and the potential temperature, respectively. The second terms, Ψ_w and Ψ_t, at the bracket in equation (3) and (4) are the functions from Businger-Dyer relations. The denominator of a natural log is the areodynamic roughness length of the ground and this value is an average quantity for the receiver's ground surface and it usually has between 0.01m and 0.1m for the typical grass surfaces. [4]

HELICOPTER NOISE SOURCES

Before the prediction of noise, the aerodynamic loadings are analyzed by the free-wake vortex lattice method and the constant vorticity contour wake model. Flow field around the blades can be reduced to the Laplace's equation in inviscid and irrotational flow. With a small disturbance assumption, rotor blades are regarded as flat plates then we can achieve the general solutions of the Laplace's equation.

Neglecting sound from the machinery for far field sound propagation characteristics, a noise database is constructed with the aerodynamically generated sound from the helicopter, especially main rotor blades.

Assumed condition that the effects of quadrupole sources are negligible then Farassat 1A formula can be used for the analysis on thickness and loading noise. The following equations illustrate the thickness noise and the loading noise. [5]

$$4\pi p'_T(\vec{x},t) = \int_{f=0}\left[\frac{\rho_0 \dot{v}_n}{r(1-M_r)^2}\right]_{ret} dS + \int_{f=0}\left[\frac{\rho_0 v_n\left(r\dot{M}_i\hat{r}_i + c_0 M_r - c_0 M^2\right)}{r^2(1-M_r)^3}\right]_{ret} dS \tag{5}$$

$$4\pi p'_L(\vec{x},t) = \frac{1}{c_0}\int_{f=0}\left[\frac{\dot{l}_i\hat{r}_i}{r(1-M_r)^2}\right]_{ret} dS + \int_{f=0}\left[\frac{l_r - l_i M_i}{r^2(1-M_r)^2}\right]_{ret} dS + \frac{1}{c_0}\int_{f=0}\left[\frac{l_r\left(r\dot{M}_i\hat{r}_i + c_0 M_r - c_0 M^2\right)}{r^2(1-M_r)^3}\right]_{ret} dS \tag{6}$$

Flight paths of the helicopter are regarded as a number of segments and the aerodynamic characteristics is considered a steady state during the each segment. In this assumed condition, the flow field around the rotor blades are analyzed and the prediction of the thickness and the loading noise are calculated. The noise database, an acoustic sphere shown in figure 2, can be constructed with these results.

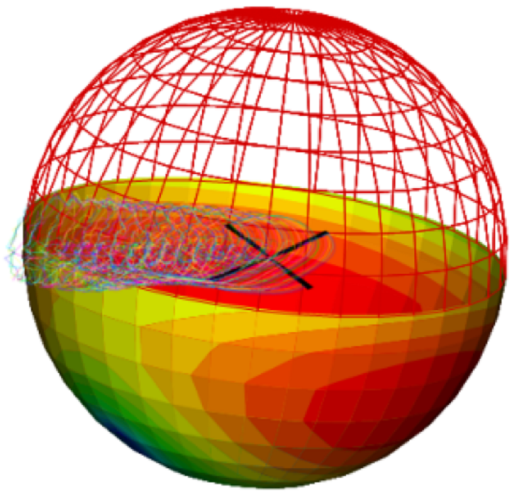

Figure 2. Description of an acoustic sphere

The acoustic sphere contains the information on the results of equation (5) and (6). The acoustic pannels are located at 7 times blade radius from the rotor hub due to neglecting the propagation characteristic in the near field. [3]

RESULTS

The figure 3 shows the grid system importing from GIS data. The arrow on the figure represents the flight path and the entire grid size is (8,000m x 8,000m). UH-60 helicopter is selected and the advance ratio is 0.185. During the simulation, we constrained the tip path plane is zero.

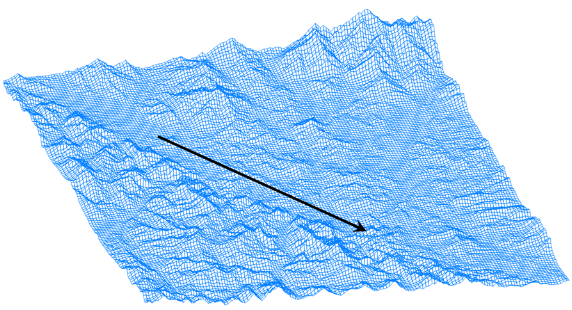

Figure 3. Grid shapes from GIS and flight path

The result shown by figure 4 is the top view and an overall SPL contour at the arbitrary time. The figure 4 is enlarged the specific area near the flight path. Although the grid shape is extremely complex, the model predicts fine results well reflecting the terrain effects, especially the diffracted wave effects.

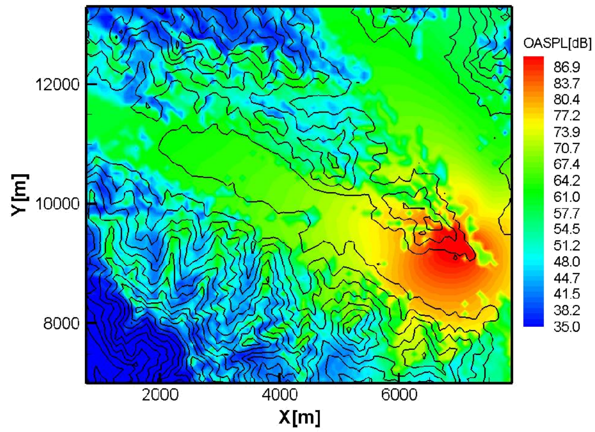

Figure 4. Overall SPL at the specific time

The results shown in figure 5 and 6 are the description of the refracted wave effects. In these cases, we applied the model to a flat terrain. The advace ratio is the same as a previous simulation and a flight height is constant at 150m. Initial position is (200m, 500m, 150m) and the end position is (950m, 500m, 150m). Figure 5 is the results of an unstable atmospheric condition and figure 6 is the results of a stable atmospheric condition.

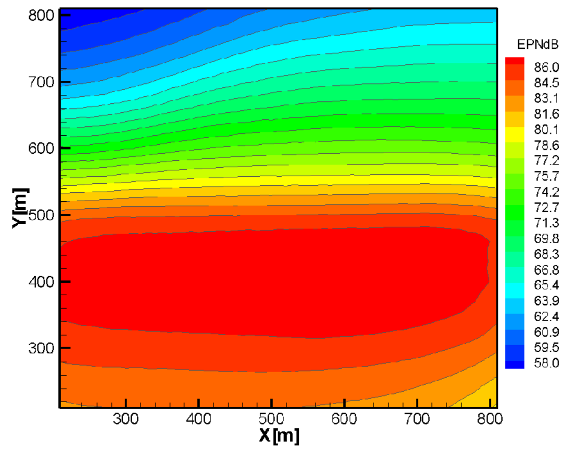

Figure 5. EPNdB in the unstable atmosphere

The left side to the direction of the helicopter is a retreating side and the right side is an advace side. Asymmetric results are reflecting the general helicopter noise directivity during a forward flight.

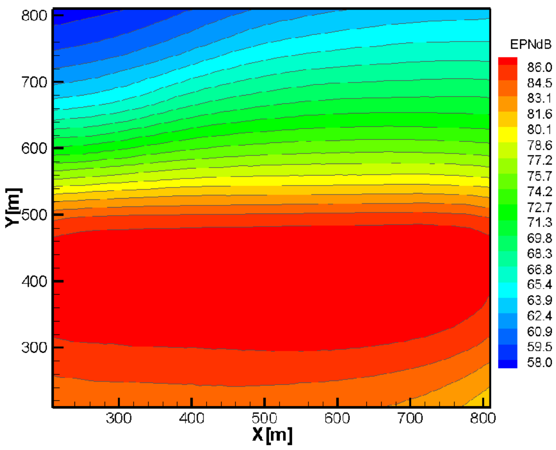

Figure 6. EPNdB in the stable atmosphere

The EPNdB at the figure 6 is slightly higher than that of the figure 5. To be more exact, the region where EPNdB has peak value in the figure 6 is broader than the figure 5. There is highest SPL region on the helicopter during the forward flight is below the tip path plane at the advance side. The area where ray with the higher acoustic energy is propagating is broader because the ray has the refracted path to the direction of the ground surface. The following figure can be shown the refracted paths. Figure 7 shows the ray paths in the stable condition. The ray trajectories from the point source are calculated.

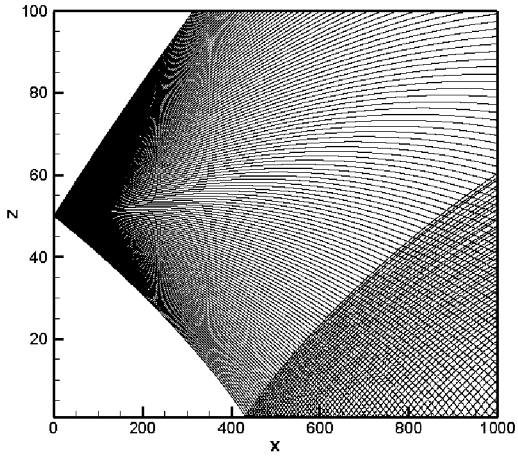

Figure 7. Ray trajectory from the point source with height 50m

The following figure 8 shows the ray paths much close to the ground surface. The number of refracting ray path is increased and there are also shown the multiple reflected waves near the surface. This result implies that if the height of the helicopter is lower, the value of SPL is increasing and the region of a highest SPL is broader due to not only the geometric distance but the effects of multiple reflected waves.

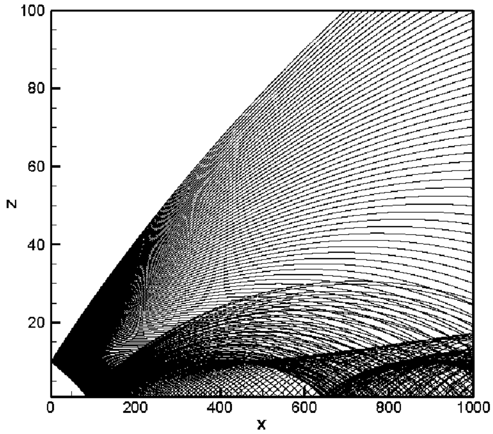

Figure 8. Ray trajectory from the point source with height 10m

CONCLUSION

The prediction model on the helicopter noise in the far field has been developed. This model contains the terrain effects and the refracting atmospheric effects. It considers the typical sound speed distributions with the atmospheric stability. This propagation model gives fine results with the effects of diffracted wave and the refracted wave. From the results, we could imply the importance on the effects of the multiple reflected waves. Further study related the relative sound pressure level on the multiple reflected waves is needed.

ACKNOWLEDGEMENT

This work was supported by the Human Resources Development of the Korea Institute of Energy Technology Evaluation and Planning (KETEP) grant funded by the Korea government Ministry of Knowledge Economy (No. 20094020100060). The present study was also funded by Core Environmental Technology Development Project in Korea Institute of Environment Science and Technology

REFERENCES

1 David A. Conner and Juliet A. Page, "*A Tool for Low Procedures Design and Community Noise Impact Assessment: The Rotorcraft Noise Model (RNM),*" HeliJapan 2002, Tochigi, Japan, 2002.
2 Eunkuk Son, Seungmin Lee, Soogab Lee, "*Stability Effects on the Sound Propagation from a Helicopter*", Proceedings of the KSNVE Twentieth Anniversary Spring Conference, pp. 193–194.
3 Eunkuk Son, Wooyoung Choi and Soogab Lee, "*Helicopter Environmental Noise Prediction on the Complicated Ground using Reflection and Diffraction Model*", ICSV15, Daejeon, Korea, 2008
4 J.A. Businger, J.C. Wyngaard, Y. Izumi, and E.F. Bradley, "*Flux-Profile Relationships in the Atmospheric Surface Layer*", J. Atmos. Sci. 28, 1971
5 F.Farassat and Kenneth S. Brentner, "*The Acoustic Analogy and the Prediction of the Noise of Rotating Blades*", *Theoretical and Computational Fluid Dynamics*, 1998