Evaluation of Lateral Attenuation for Aircraft Takeoff-roll Noise by Multi-point Measurement

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ABSTRACT

It is indispensable to consider lateral attenuation for aircraft noise prediction around airport. In 2000's, we proposed a calculation method to predict lateral attenuation under various meteorological conditions by modifying the SAE AIR 1751 ("1751M"). Afterwards, a lot of new types of aircraft or engines have been launched, and comparing results of noise prediction with measurements have suggested that "1751M" gives a bit underestimation of the values of lateral attenuation. Thus, we have started the study to check the validity of lateral attenuation equations for new types of aircraft. At first, the examination on the validity of lateral attenuation equations using long-term noise monitoring data at Narita airport have been carried out. Next, we planned a multi-point and short-term measurement to complement with long-term measurement for the detailed investigation. The multi-point noise measurement was carried out continuously 7 days in different seasons at Narita airport. In the measurements, aircraft noise was observed at different lateral distances of 190 m - 1460 m. 1/3 octave band analysis results of every moment was recorded at each point. This paper introduces parts of results of over-ground lateral attenuation.

Keywords: Airport noise, Prediction model, Meteorological conditions
I-INCE Classification of Subjects Numbers: 24.6, 52.2, 76.1.3

1. INTRODUCTION

It is indispensable to consider lateral attenuation for aircraft noise prediction around airport. The well-known SAE AIR1751 (1) was introduced in the 1980's, but it had been said to bring a little overestimation of the lateral attenuation since the 90's. Thus, we examined the validity of AIR1751 equation using the results of noise monitoring stations which were installed around Narita airport. At inter-noise congress 2003 to 2006 (2, 3, 4), we introduced that lateral attenuation was strongly affected by meteorological conditions, especially vector wind. Further, we proposed a modified equation of AIR1751 (1751M) allowing for various conditions of vector wind and temperature gradient, which was modified based on the measurement results. Afterwards, a lot of new types of aircraft or engines have been launched, and comparing results of noise prediction with measurements have suggested that 1751M gives a bit underestimation of the values of lateral attenuation. On the other hand, the SAE issued a new method for predicting lateral attenuation as AIR 5662 (5) in 2006 which is a reformulation of AIR1751 and gives a bit higher value of lateral attenuation than that of 1751M in the case of aircraft with engines mounted under the wing. 1751M has advantage of applicable under various meteorological conditions. Therefore, we decided to perform a comprehensive re-consideration of the lateral attenuation in the noise prediction model. At first, the examination on the validity of lateral attenuation equations using long-term noise monitoring at Narita airport have been carried out (6). We have anticipated that the 1751M would make the over-ground lateral attenuation value for the current aircraft type show a little

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underestimation, but the results of measured over-ground lateral attenuation are even lower, contrary to what we have expected. The results of noise measurement at various distances is necessary because there are currently only two different distances in long-term monitoring which therefore cannot give a very detailed insight. Next, we planned a multi-point and short-term measurement to complement with long-term measurement for the detailed investigation. The multi-point noise measurements are carried out continuously 7 days in each of 4 seasons at Narita airport. This paper introduces parts of measurement results of the lateral attenuation during over-ground propagation.

2. MULTI-POINT NOISE MEASUREMENT AT NARITA AIRPORT

2.1 Outline of Multi-Point Noise Measurement

A series of multi-point noise measurements at Narita airport were carried out in 3 seasons (in August, October 2015 and February 2016), and additional measurement was carried out in May 2016. In each measurement, L_{AS} and 1/3 octave band level of every 0.1 s were continuously recorded for 7 days at 8 different points. Figure 1 shows schematic image of site location of the measurement points. The measurement points were arranged at different distance of 186 m - 1456 m along measurement line which was crossed to a point of 500m from runway "34L" end. Takeoff-roll noise on runway "34L" was observed at these points.

Microphones of sound level meter (Rion NA-28 or NL-62/52) were placed at 1.5 m above ground. However at Pt6 in summer and winter, microphone was placed at 4 m above rooftop surface of 4 m height building. Meteorological conditions (wind direction, wind speed and air temperature) were also measured at 2 m and 40 m in height near airport. Additionally, in order to detect the aircraft position of every moment, a four-channel microphone array for DOA (direction-of-arrival) estimation using cross correlation technique (7) was placed at Pt1.

Figure 2 shows photographs of microphone at each measurement point. At Pt1 and Pt2, ground surface between the microphone and the runway was covered with grass. Pt3, Pt4, Pt6, Pt7 and Pt8 were located at the open space in suburban area near the airport. In AIR5662 or 1751M, the over-ground attenuation is defined as a constant value at lateral distance greater than 914 m (=3000 ft). Pt5 was arranged on the measurement line in the vicinity of the distance 914 m, but have just placed into the woods.

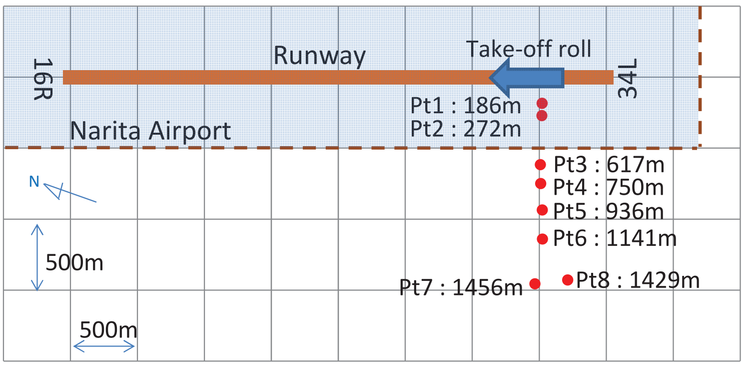


Figure 1 – Schematic image of site locations of multi-point measurement

2.2 Variation of Sound Pressure Level due to Meteorological Conditions

The number of B767-300 data was maximum percentage (17%) of total number in the measurement. In this section, we will focus on data of B767-300 takeoff-roll noise. Figure 3 shows temporal variation of L_{ASmax} and L_{AE} at typical point (Pt1, Pt4, Pt6 and Pt8). It also shows weather conditions. The vector wind speed along the measurement line is calculated based on wind speed and direction which measured at 2 m in height. The temperature difference is calculated as difference of the temperature measured between 40 m and 2 m in height. The classification of the vertical air temperature gradient was defined as follows: "Lapse" is the temperature difference between 40 m and 2 m in height -0.5 °C or less, "Neutral" is ±0.5 °C, "Inversion" is +0.5 °C or more.

In figure 3, we can see that level variation is occurred and the variation becomes large in the long distance. The vector wind speed changed between -2 m/s (upwind) to +6 m/s (downwind) during measurement term. It tends to large level at downwind condition, and small level at upwind condition. The temperature gradient "Neutral" was most frequently observed. "Lapse" was the second most, and was observed in daytime. "Inversion" was less frequently observed, and was observed in morning, evening or night time. At "Inversion" it tends to large level in far point.

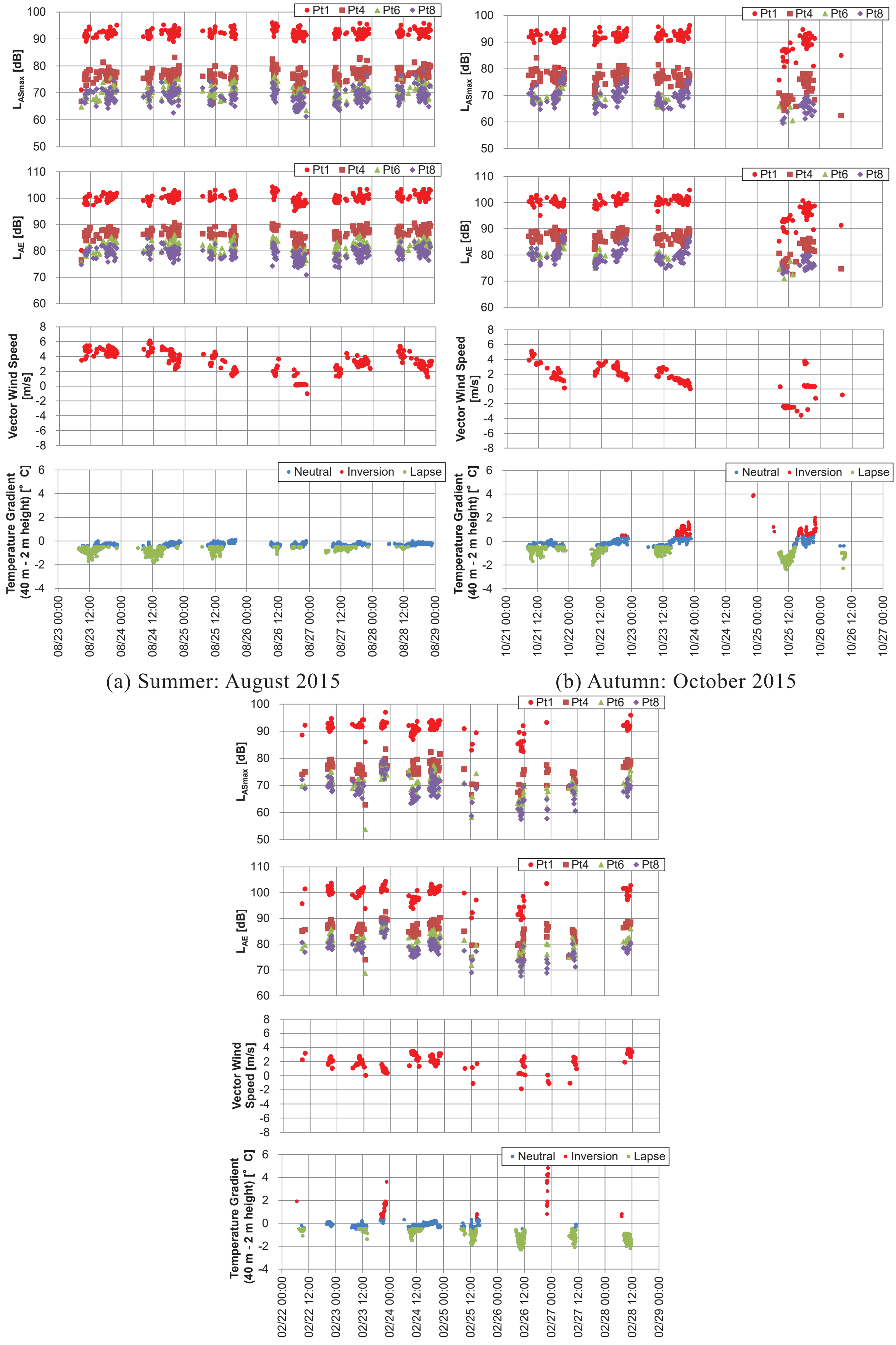
Pt1 Pt2

Pt3 Pt4

Pt5 Pt6 (Summer and Winter)

Pt7 Pt8

Figure 2 – Photographs of microphone at each measurement point



(a) Summer: August 2015

(b) Autumn: October 2015

(c) Winter: February 2016

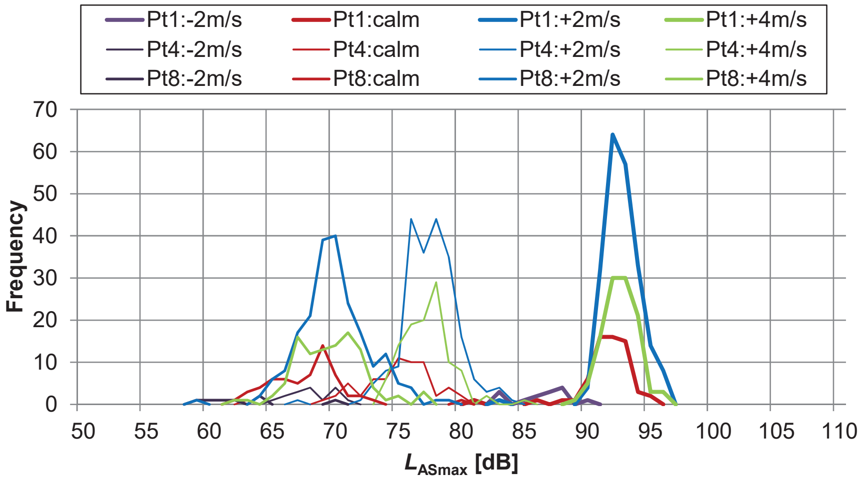
Figure 3 – Temporal changes of L_{ASmax}, L_{AE} and meteorological condition (B767-300 takeoff-roll)

3. METEOROLOGICAL EFFECT OF OVER-GROUND PROPAGATION

3.1 Effect of Vector Wind Speed

In order to investigate the effect of the vector wind speed, the results of measurement in neutral condition of temperature gradient have been analyzed. However, number of data in "upwind and neutral" was very few, so the data in the "upwind and lapse" addition to the "upwind and neutral" have been analyzed.

Figure 4 shows frequency distribution of L_{ASmax} and L_{AE} of B767-300 takeoff-roll between vector wind speed classes at typical point (Pt1, Pt4 and Pt8). The vector wind speed classes are classified as follows: "-2 m/s" (-3 ~ -1 m/s), "calm" (±1 m/s), "+2 m/s" (+1 ~ +3 m/s), "+4 m/s" (+3 ~ +5 m/s). The downwind condition was the majority of the data. "+2 m/s" class was most frequently observed. "+4 m/s" class was the second most. It seems that there was no difference in the distribution of the level between "+2 m/s" and "+4 m/s". "Calm" class was less frequently observed. The data were distributed towards about 2 or 3 dB smaller level than the downwind classes. "-2 m/s" class in upwind was very less frequently observed. The data were distributed towards about 5 dB or smaller level than the downwind classes.



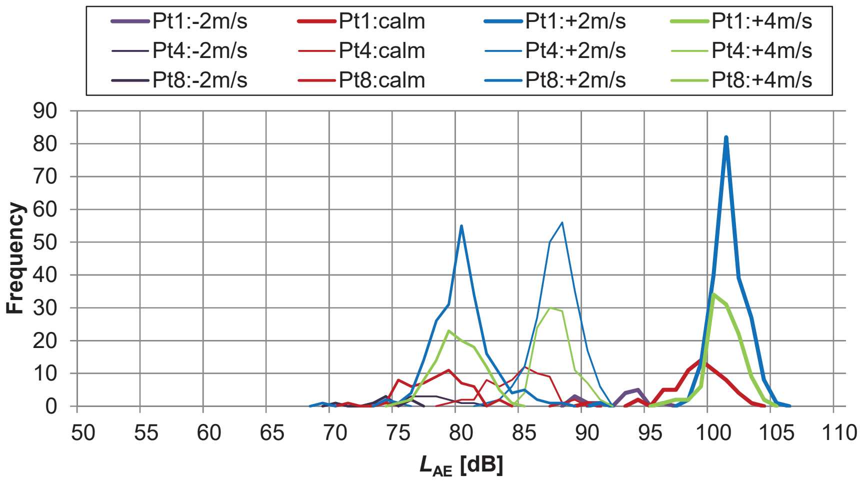


Figure 4 – Frequency distribution of L_{ASmax} and L_{AE} between the vector wind speed class (B767-300 takeoff-roll)

Figure 5 shows relationship of L_{ASmax} and L_{AE} with distance between the vector wind speed classes. Arithmetic mean values of each vector wind speed class were plotted in the figure. There is no much difference in the trend of distance attenuation between L_{ASmax} and L_{AE}.

In the upwind condition (-2 m/s), levels measured at each point were 3 ~ 7 dB smaller compared to the calm condition. In the downwind condition, much difference is not seen in the level between +2 m/s and +4 m/s. The levels measured in downwind condition at each point were 1 ~ 4 dB large compared to the calm. In Pt3, Pt5 and Pt7, it is shown that the levels are smaller than the other points. There is a possibility of influence of any obstacles like as the terrain or the woods to the propagation.

Afterward, in order to investigate the relationship between the vector wind and the lateral attenuation for L_{ASmax}, it was calculated the lateral attenuation of individual flight in the following procedure.

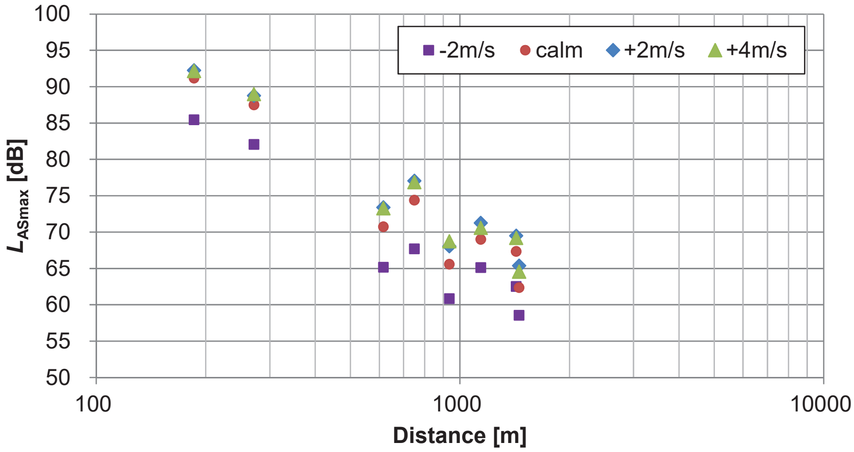
(a) Obtain sound spectrum for individual takeoff-roll at the time of observed L_{ASmax} in Pt1.

(b) Calculate sound source spectra (1/3 octave band spectra of distance 1 m from sound source) by applying adjustments for the propagation properties along the ground surface (using the analytical solution of the effective flow resistivity of ground surface as 200 kPa s/m^2), the spherical spreading and the atmospheric absorption.

(c) Calculate L_{ASmax} at each measurement point, by applying adjustments for spherical spreading and atmospheric absorption to the sound source spectra obtained in the step (b).

(d) Calculate the lateral attenuation as the difference between the measurements and estimations in (c) at each measurement point.

Figure 6 shows a comparison of over-ground lateral attenuation calculated by measurement results and the equations (AIR5662 and 1751M) at each vector wind speed class. In the results of Pt1, 2, 4, 6 and 8, we can see that the lateral attenuation calculated using measurement results in the downwind condition is similar to the "1751M (downwind)". And the lateral attenuation in the calm and upwind conditions, except for Pt8, is a little lower than "1751M (calm and upwind)". In Pt8, the lateral attenuation in upwind condition is less than that obtained at other points. On the other hand, in the results of Pt3, 5 and 7, the lateral attenuation is large than other points. There is a possibility of influence of any obstacles like as the terrain or the woods to the propagation.



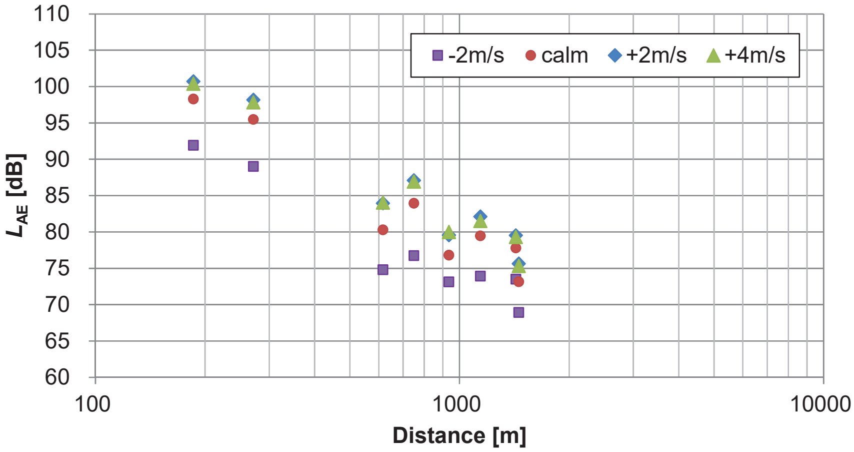


Figure 5 – Relationship of L_{ASmax} and L_{AE} with distance between the vector wind speed classes (B767-300 takeoff-roll)

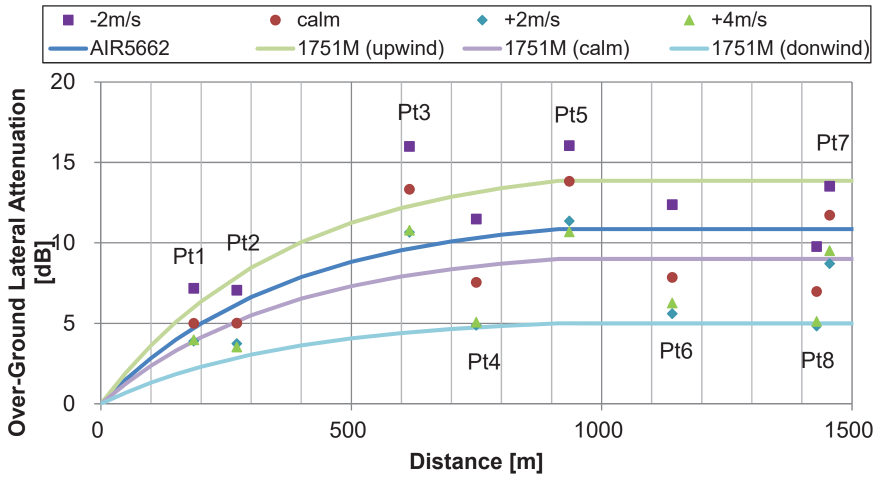


Figure 6 – Comparison of over-ground lateral attenuation calculated by measurement results and equations (AIR5662 and 1751M) at each vector wind speed classes (B767-300 takeoff-roll, L_{ASmax})

3.2 Effect of Vertical Temperature Gradient

In order to investigate the effect of the vertical air temperature gradient, the results of measurement in all vector wind speed have been analyzed. Figure 7 shows frequency distribution of L_{ASmax} and L_{AE} of B767-300 takeoff-roll between the temperature gradient classes at typical point (Pt1, Pt4 and Pt8). "Neutral" was most frequently observed. "Lapse" was the second most. The data were distributed towards about 2 or 3 dB smaller level than "Neutral". "Inversion" was less frequently observed. The data were distributed towards large level than "Neutral".

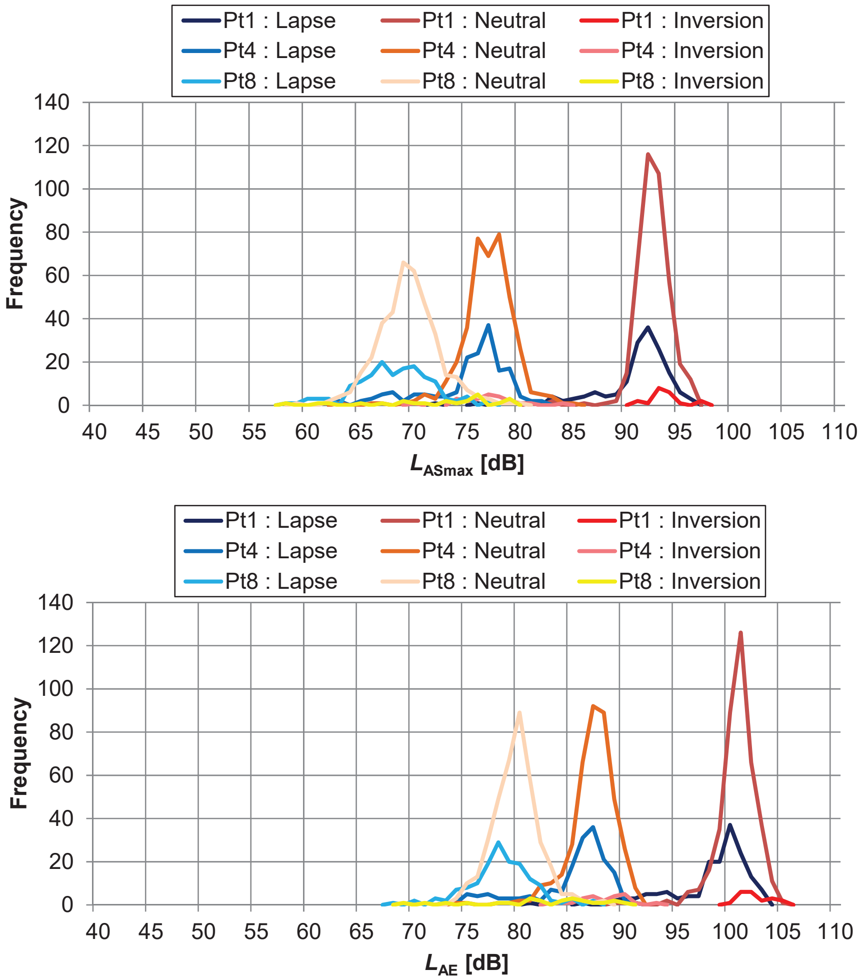


Figure 7 – Frequency distribution of L_{ASmax} and L_{AE} between the temperature gradient classes (B767-300 takeoff-roll)

Figure 8 shows relationship of L_{ASmax} and L_{AE} with distance between the temperature gradient. Arithmetic mean values of each temperature gradient were plotted in the figure. As well as the vector wind speed, there is no much difference in the trend of distance attenuation between L_{ASmax} and L_{AE}. The levels measured in "Lapse" at each point were -1 ~ -3 dB compared to "Neutral". The levels measured in "Inversion" were 0 ~ +4 dB compared to the "Neutral".

Afterward, in order to investigate the relationship between the temperature gradient and the lateral attenuation for L_{ASmax}, it was calculated the lateral attenuation of individual flight in the procedure described in previous section. Figure 9 shows a comparison of over-ground lateral attenuation calculated by measurement results and various equations at each temperature gradient.

In the results of Pt1, 2, 4, 6 and 8, we can see that the lateral attenuation calculated by measurements in "Neutral" is near or a little small to "1751M (calm)". "Lapse" is a little large and "Inversion" is a little small than "Neutral". In the results of Pt3, 5 and 7, the lateral attenuation is large than other points as same as previous chapter.

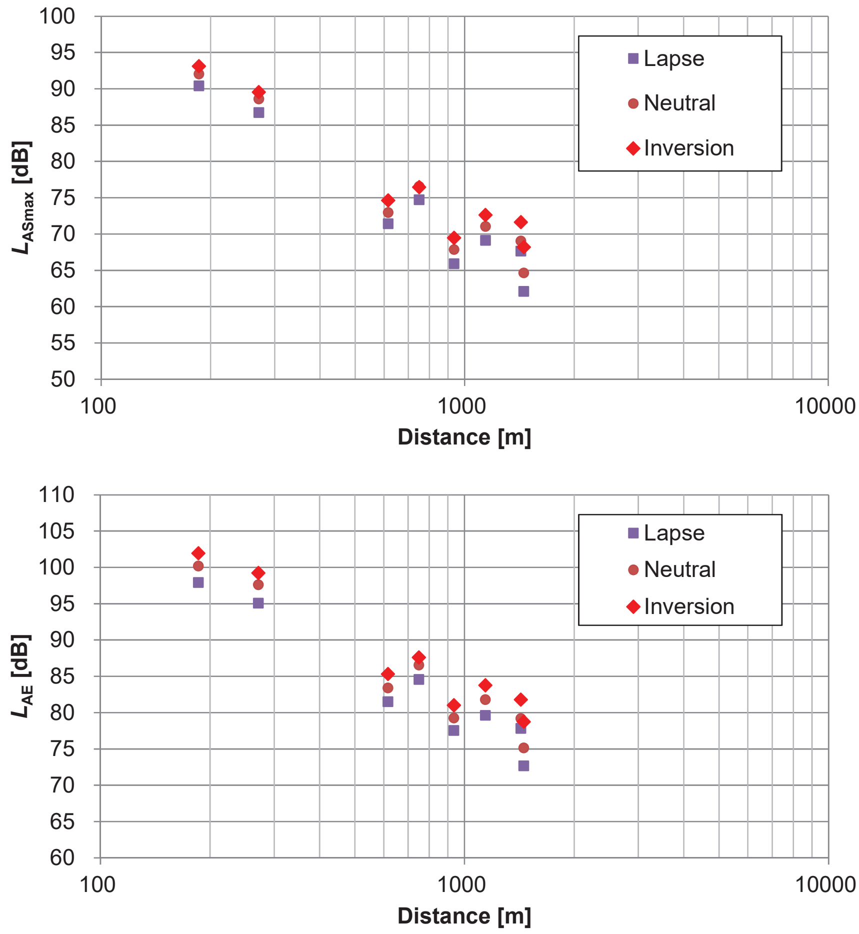


Figure 8 – Relationship of L_{ASmax} and L_{AE} with distance between the temperature gradient (B767-300 takeoff-roll)

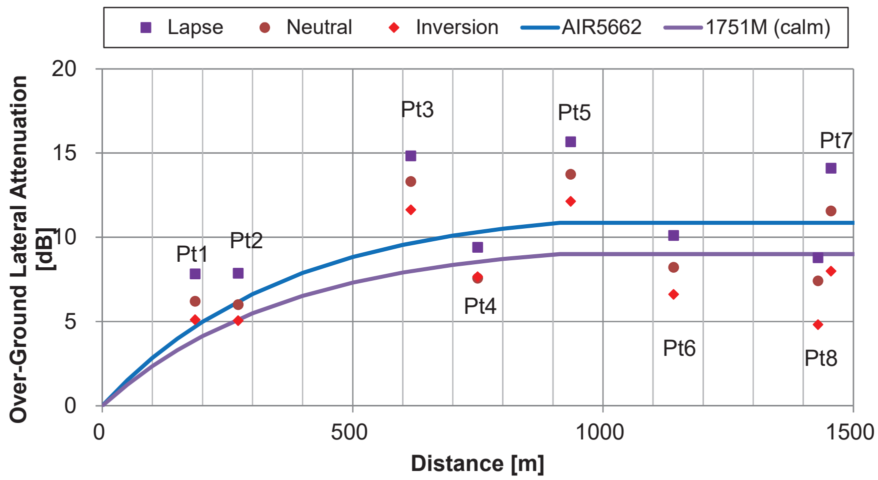


Figure 9 – Comparison of over-ground lateral attenuation calculated by measurement results and equations (AIR5662 and 1751M) at each temperature gradient (B767-300 takeoff-roll, L_{ASmax})

4. COMPARISON OF PROPAGATION CHARACTERISTICS BETWEEN AIRCRAFT TYPES

In order to compare of propagation characteristics between aircraft types, the relative L_{ASmax} and L_{AE} were calculated relative to level measured at pt1. Figure 10 shows relationship of L_{ASmax} and L_{AE} relative to level measured at Pt1 with distance between major aircraft types. Arithmetic mean values at each point were plotted in the figure. There is no much difference in the trend of the attenuation in distance between L_{ASmax} and L_{AE}. We can see that there is a difference in the distance attenuation characteristic depending on the aircraft type. The maximum difference between types is 3.2 dB at Pt8. Distance attenuation of B738 is smallest, and the attenuation of the B744 is the largest. B738 and MD11 are less distance attenuation than B763. The distance attenuation of B788, A320, B748 and A388 are similar to B767. These aircraft types are relatively recent designs. A333, B772, B773 and B744 are a little large distance attenuation than B763. These differences in aircraft types may be due to differences in the frequency characteristics or the directivity of the sound source.

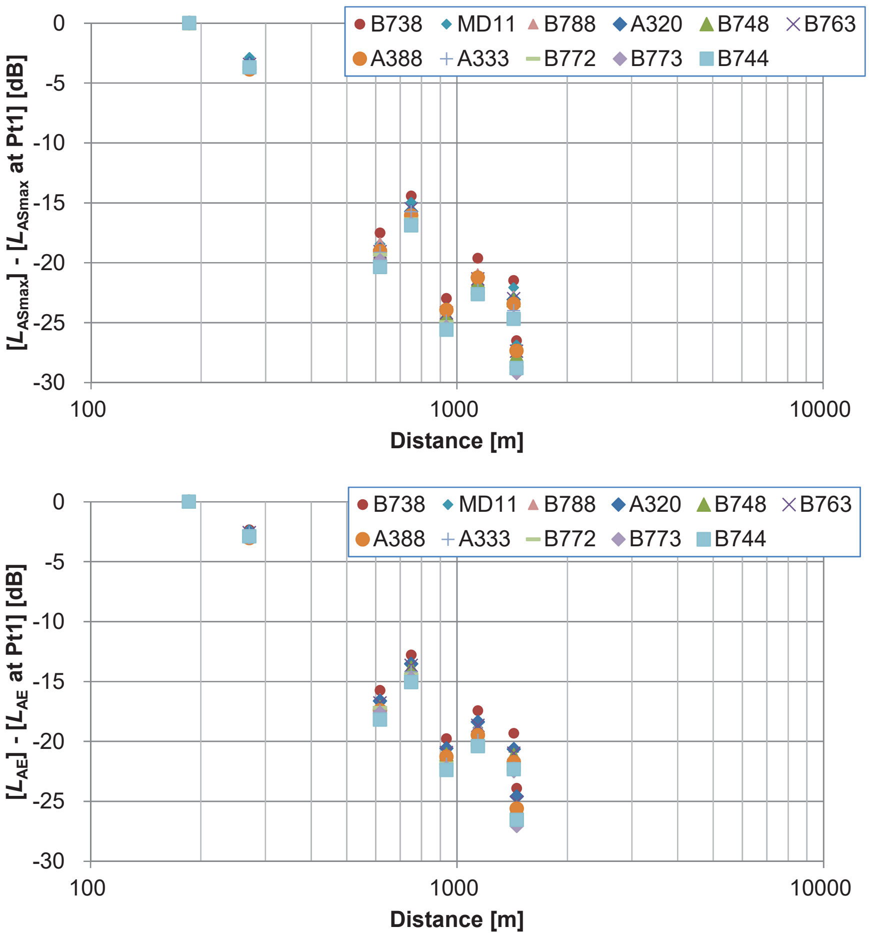


Figure 10 – Relationship of L_{ASmax} and L_{AE} relative to level measured at Pt1 with distance between the aircraft types

5. CONCLUSIONS

Multi-point and short-term measurements were carried out to complement with long-term measurement for the detailed investigation. In each measurement, L_{AS} and 1/3 octave band level of every 0.1 s were continuously recorded for 7 days at 8 different points The measurement points were arranged at different distance of 186 m - 1456 m along measurement line.

In the measurement, L_{ASmax} and L_{AE} variation due to meteorological effects was observed. In the upwind condition (-2 m/s), levels measured at each point were 3 ~ 7dB smaller compared to the calm condition. In the downwind condition, much difference is not seen in the level between +2 m/s and +4 m/s. The levels measured in downwind condition at each point were 1 ~ 4dB large compared to the calm. As a result of organizing a temperature gradient, the levels measured in "Lapse" at each point were -1 ~ -3 dB compared to "Neutral". The levels measured in "Inversion" were 0 ~ +4 dB compared to the "Neutral". In comparing of propagation characteristics between aircraft types, there is a difference in the distance attenuation characteristic depending on the aircraft type. The maximum difference between types is 3.2 dB at distance of 1429 m.

In the future, we will proceed with the investigation of the following issues that were found in this study:

- In the results of Pt3, 5 and 7, the lateral attenuation is large than other points. There is a need to clarify the cause of the level difference between the points.
- In this investigation, the value of the lateral attenuation was evaluated using maximum sound pressure level (L_{ASmax}). It is necessary to consider how suitable it is in the case of evaluation using sound exposure level (L_{AE}).

ACKNOWLEDGMENTS

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