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NOISE CONTROL FOR A BETTER ENVIRONMENT

Verification of comparison between measurement and prediction results of lateral attenuation derived from equations used in aircraft noise prediction

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ABSTRACT

It is indispensable to take account of lateral attenuation when modelling airport noise. Our 1751M equation is a modified reformulation of AIR 1751 that we proposed 15 years ago. It is useful under various weather conditions expressed by vector wind and temperature gradient. Furthermore, when ground-to-ground sound propagation is expressed, the evaluation value is a little less than AIR 5662 which was proposed in 2006 by SAE. Also, it showed that air-to-ground lateral attenuation rapidly decreased when elevation angles of sound arrival direction became higher than about 12 degrees. Since then, however, much time has passed and a lot of new types of aircraft have been introduced, so rechecking of the validity of 1751M for current aircraft models is needed. Thus, in recent years, we have examined whether existing equations such as SAE/AIR 5662 and our 1751M can correctly evaluate lateral attenuation for flyover noise of late model aircraft, using results of long-term noise monitoring and repeated short-term noise measurements obtained. This paper describes the verification of comparison between measurement results and prediction results which by using multiple lateral attenuation equations, (mainly with elevation angles of 10 - 30 degrees), shows a remarkable difference between 1751M and 5662.

Keywords: Aircraft Noise, Modeling, Lateral attenuation, Meteorological conditions
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1. INTRODUCTION

It is necessary to take lateral attenuation (LA) into account for airport noise modelling. Lateral attenuation is defined as the difference in level between the sound observed at a location directly under the flight path and that at another location to the side of the aircraft at the time of closest approach. The lateral attenuation is defined by two regression equations, one is for the ground-to-ground propagation (GTG) and the other is for the air-to-ground situation (ATG). The total LA given in dBA expresses in a form of a product of two components. The well-known SAE/AIR 1751 [(1)] equation was introduced in the 1980's, but since the 90's, it has been said to bring a little overestimation.

Our former study which commenced in the early 2000's, used the results obtained from noise monitoring stations which were installed along the runway of Narita Airport. These results showed that lateral attenuation is strongly affected by meteorological conditions, especially vector wind. Further, at each Inter-noise congress from 2003 to 2006 [(2, 3 & 4)], we proposed adopting the modified equation (1751M) which can be used for various conditions of vector wind and temperature gradient.

However, in the past decade, new types of aircraft and engines have been introduced which have brought change to noise exposure around airports. For example, when the 1751M was first proposed in the early 2000's, the most commonly operated type of aircraft in Japan was the B747-400, which was therefore the main target of our studies. Nowadays, many B747-400's have been phased out, whereas new twin-engine aircraft such as the B777 and B787 which all have high bypass ratio engines, have rapidly increased in operation movements. In addition, the values of lateral attenuation using the 1751M have also resulted in a little underestimation.

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 AIR 1751 and gives a bit higher value of lateral attenuation than that of 1751M. Therefore, we decided to perform a comprehensive re-consideration of the lateral attenuation in the noise prediction model, because 1751M is still useful for calculating under various meteorological conditions.

At Inter-noise congress 2016, we reported the first step of the re-examination. We revealed lateral attenuation of Ground-to-Ground (GTG) propagation, using results of a long-term monitoring system installed around Narita Airport [(6)]. From the re-examination's result, the LA/GTG of the large size four engine aircraft such as B747-400's are consistent with former results of 1751M's consideration. However current aircraft models' (twin engine low noise Jet) LA/GTG results are smaller than the previous ones.

Secondly, we carried out multiple short-term measurements at plentiful measurement points at various airport in Japan including Narita, because of that examination was limited to only two unattended monitoring stations. From the results, although it was found that the tendency of LA/GTG varies depending on the environment around the measurement point (difference in acoustic characteristics) or ground surface situation in sound propagation, LA/GTG is considered to be almost consistent with the 1751M/GTG [(7,8)].

Further, we carried out an examination of air-to-ground lateral attenuation, applicable to various meteorological conditions by using data of long-term noise monitoring at Narita. In inter-noise 2017 [(9)], we reported that from the results of its examination, estimated LA/ATG using noise monitoring data is close to LA/ATG values from the 1751M equation. Also, there is a distinct difference in the value of LA/ATG at the area of elevation angles lower than 30° between results from lateral attenuation equations AIR 5662 and 1751M.

Furthermore, we examined the validation of noise prediction results among various lateral attenuation equation comparison with the results of long-term noise monitoring stations around the Narita Airport. This paper describes which LA equation has the least divergence compared to the actual situation of noise exposure.

2. REVIEW OF LA/GTG EXAMINATION

2.1 Examination using long-term monitoring observations at Narita Airport

First, here is a brief review of the results of analysing lateral attenuation of Ground-to-Ground (GTG) propagation, using results of a long-term monitoring system installed around Narita Airport.

Figure 1 shows a comparison of 'LA/GTG relationship with vector wind' among various aircraft types observed from take-off rolling on the runway in FY2012 – 2013, measured at a point 710m from the runway. It also shows results from FY2000 of B747-400's which was the basis for the determination of 1751M.

The same calculation procedure for lateral attenuation was used when constructing 1751M. LA/GTG was calculated as the difference between the noise measurements and noise level estimations by applying adjustments for spherical spreading and atmospheric absorption to the A-weighted sound source spectra, at each of the monitoring stations. The sound source spectra (1/3-octave band spectra relative to distance 1m) was obtained from analysing the results of two separate one-week noise measurements taken under the take-off flight path just after take-off (Microphone height = 4m). Further it classified into individual categories of aircraft model, engine and flight distance (long-range, mid-range and short-range).

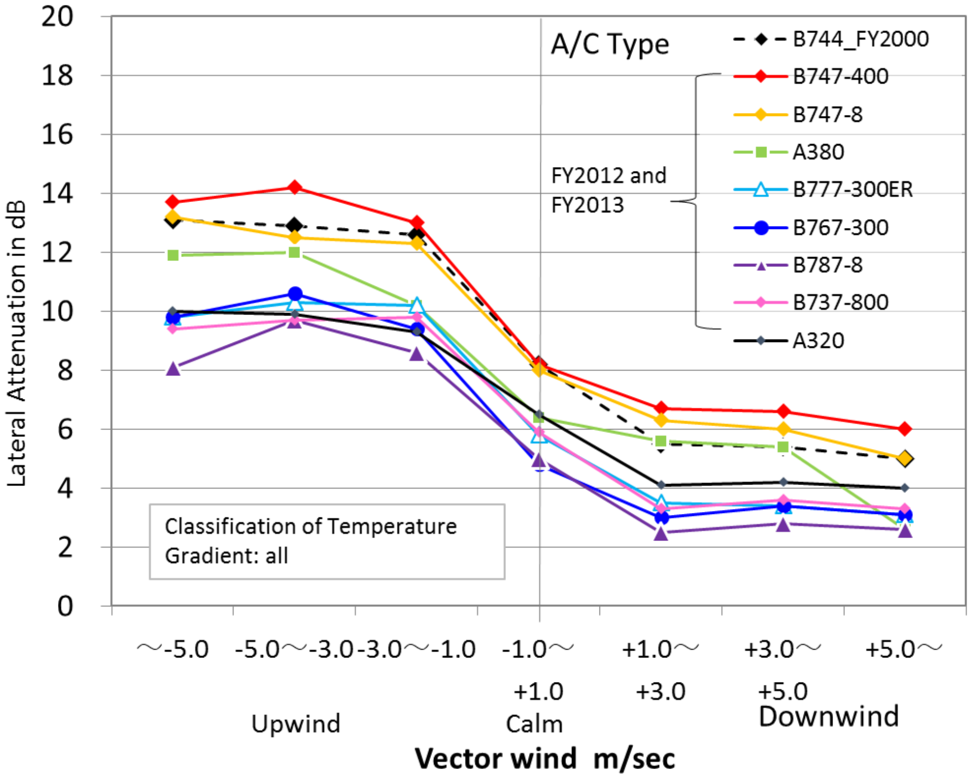

Figure 1 –- Relationship between LA/GTG FY2012-2013 among various aircraft types, together with that of B747-400's FY2000 data, measured at a point 710m from the runway.

From the figure, the LA/GTG of the large size four engine aircraft such as B747-400's or B747-8's are consistent with the former results of B747-400 FY2000's (dotted line shown in figure). We can see a clear tendency that LA/GTG is higher upwind than downwind irrespective of aircraft types, and it has not changed from the previous investigation results. The rest of the current aircraft models' (mid or small sized twin engine such as the B777, B787, B767, B737 or the A320) LA/GTG results are smaller than the current and previous B747's. The reason for the difference between models is not clear. It might be the difference between four engine and twin engine, or it might be the difference between aircraft size such as a large or a medium or small-sized plane. Furthermore, the magnitude of the source noise level might also be affecting the difference. Either way it is ambiguous.

2.2 Examination using short-term measurements at various airport in Japan

As a section 2.1 result, it was found that the value of LA/GTG estimated from obtained noises is a little lower than the value of 1751M equation in current twin engine aircraft, although it is almost agreement with 1751M in four engine aircraft. However, that examination was limited to only two unattended monitoring stations. Thus, we carried out multiple short-term measurements at plentiful measurement points at four airports in Japan including Narita as follows.

Narita Airport: There are many flight operations at international airports representing Japan. The airport is located 60km distant from Tokyo, in suburb area, but there are also some residential areas. We carried out 7 days short-term measurements every season with 8 measurement points selected along the perpendicular to the runway-A in a little height undulation within 7m. These were mainly selected grass field area, but some points were at residential area.

Sendai Airport: Medium sized airport in northern territory of Japan, mainly flight by mid-sized twin engines or less sized aircraft. We curried out 7 days short-term measurement with 6 point located along the perpendicular to the runway with an area of flat rice field.

Kagoshima Airport: Medium sized airport in southern territory of Japan, mainly flight by mid-sized twin engines or less sized aircraft. We curried out 5 days short-term measurement with 4 point located along the perpendicular to the runway with an area of flat farmland field.

Osaka Airport: It is one of the main airports for domestic flights in Japan, which is located about 10km north-west of Osaka's city center. In the airport's surrounding area, residential areas are dense, and it has had serious noise issues since the 1960's. Our short-term measurement was carried out 5 day with 7 point located along the perpendicular to the runway. The measurement area is in urban area where many houses and factories, so we set the microphone to open field as much as possible. Height undulation of measurement area is within 3m, but 7m noise embankment for noise mitigation is located along the runway.

Figure-2 show a comparison of LA/GTG estimated from four airport's short-term measurements with equation value of for lateral attenuation 1751M and SAE/AIR5662. Note, AIR 5662 does not include 1.49 dB of engine installation effects for airplanes with wing-mounted jet engines. The figure divided into three groups dependent of vector wind conditions, ' Upwind '(upper figure), 'Calm' (mid figure) and 'Downwind' (lower figure), respectively.

From these results, LA / GTG value varies widely depending on the characteristics of the airport area. Also, the LA / GTG changes depending on the wind direction. Roughly speaking, the results of LA / GTG investigated at the four airports, its tendency agrees with the result calculated from the evaluation formula 1751M. Especially in case of flat and uniform farmland field at Sendai Airport, it agrees well. With regard to LA/GTG in urban (Osaka) and suburban areas (Narita), the results vary widely so that some of the measurement points were thought to include the effects of diffraction attenuation caused by undulations or buildings. The value derived from the equation 5662 tends to match in calm conditions, but it not in agree at downwind conditions.

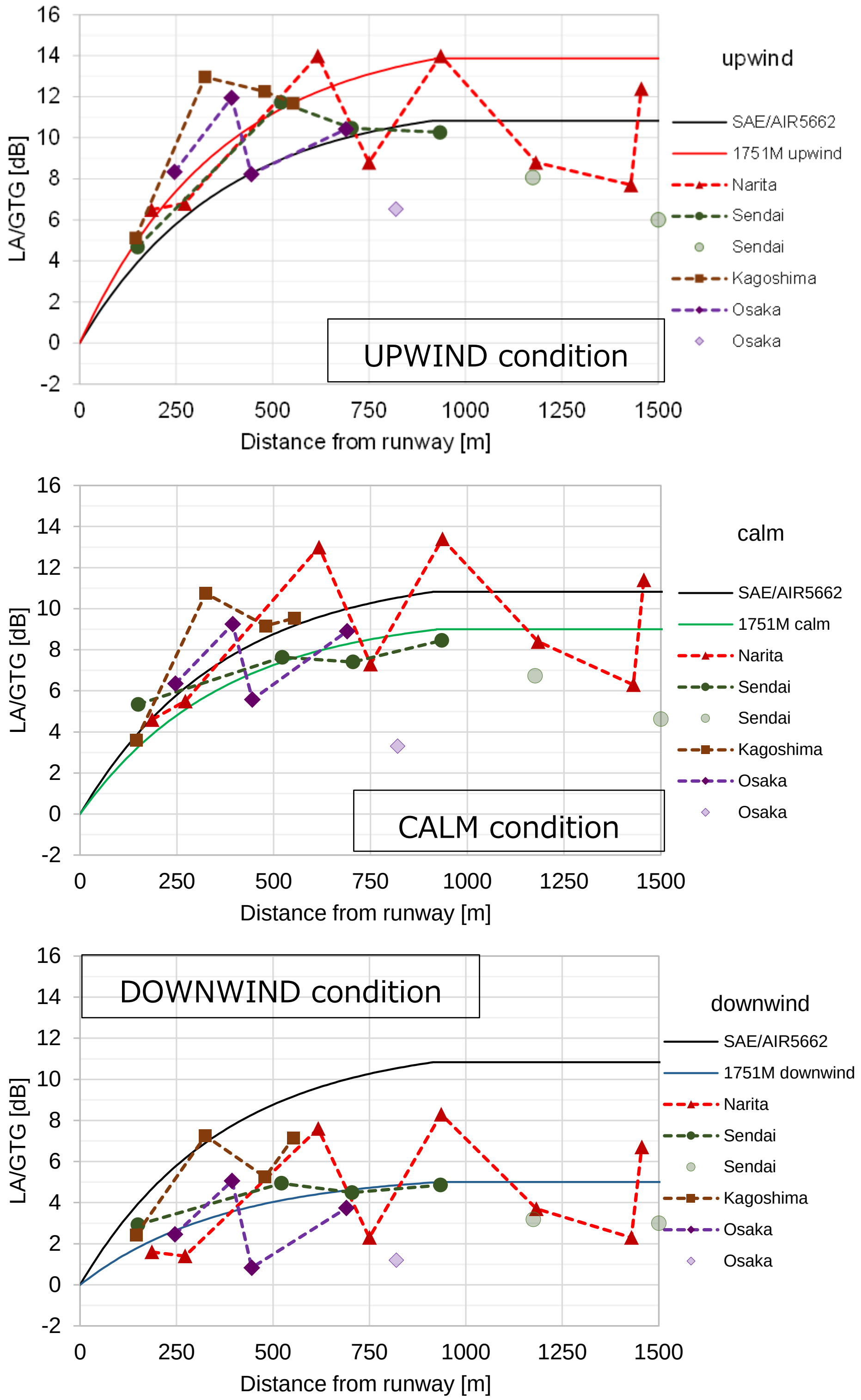

Fig. 2 – Comparison of LA/GTG in downwind at 4 airports with existing formulas for LA/GTG

3. REVIEW OF LA/GTG EXAMINATION

Figure-3 shows comparison of the Air-to-Ground (ATG) component of lateral attenuation among the three equations: AIR 1751, 1751M and AIR 5662.

The LA/ATG estimated by AIR1751 is larger than the other LA evaluation equations, 13.86 dB at an elevation angle of 0 degree (i.e., GTG), LA / ATG decreases as the elevation angle increases, and 0 dB at elevation angle 60 degrees. Engine installation effects or shielding effect from the fuselage was not considered when formulating the AIR 1751. Several studies undertaken after the 1990's have revealed that the SAE/AIR 1751 overestimates the amount of lateral attenuation.

The AIR 5662 takes this into consideration by calculating differently for each type of aircraft engine mounting location (fuselage or wing or propeller-driven) and depression angle. The red line in the figure shows as the LA/ATG of engine wing-mounted aircraft. 12.24dB at an elevation angle of 0 degrees which is a bit lower value of lateral attenuation than that of the 1751, LA / ATG decreases as the elevation angle increases, and becomes 0 dB at an elevation angle of 40 degrees. LA/ATG takes a slightly negative value between 30 and 75 degrees, in consideration of the engine-installation effects that is reinforcement from the reflection off the wing surface.

The validity of the LA/GTG equation was examined using the results of long-term noise monitoring in FY 2002 at Narita airport. From the results, we found that the LA/ATG rapidly decreases as the elevation angle increases. Also, LA/ATG is negligible at elevation angles greater than around 10 - 15 degrees. Based on these results, we proposed LA equation 1751M. It can express the evaluation of LA under vector wind conditions, i.e. Upwind, Calm and Downwind. The calm wind condition is also applicable representative of a long-term average. It evaluates LA/GTG of 9dB at an elevation angle of 0 degrees, and 0 dB at an elevation angle of 12 degrees. In the case of downwind condition, it evaluate LA/GTG of 5dB, further, in the case of upwind condition, LA/GTG is estimated to be 13.86dB, the same value derived by AIR 1751. In the analysis results at the time, although there was the tendency similar to the reinforcement effect due to the wing surface reflection, it was not taken account in the equation of 1751M because of no clear basis.

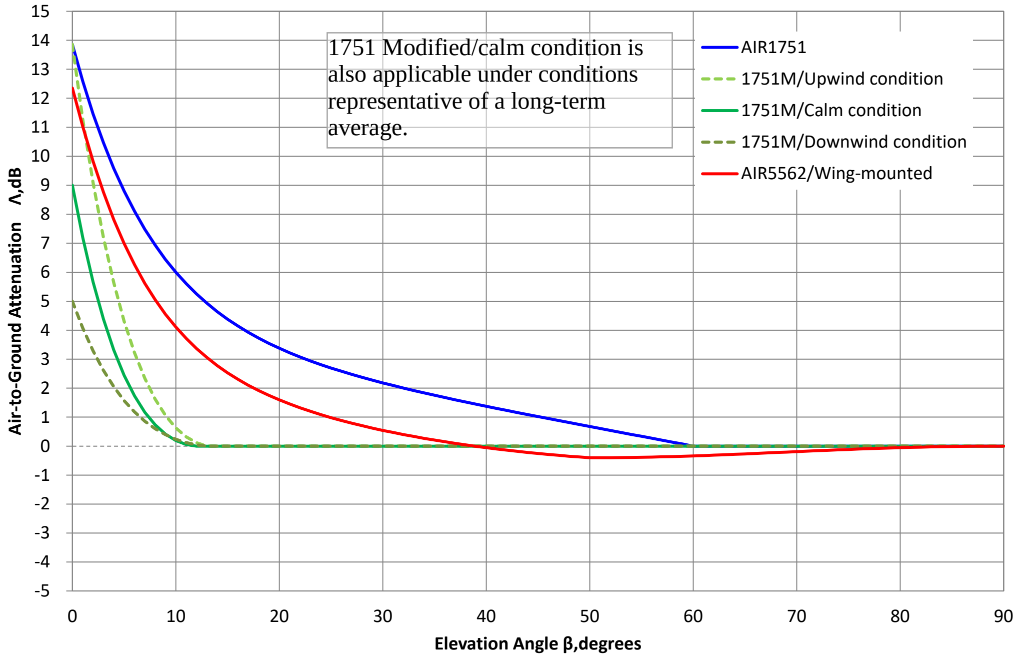

Figure 3 - Comparison of the Air-to-Ground (ATG) component of lateral attenuation for long distance (>914m) among the three equations: AIR 1751, 1751M and AIR 5662 for wing-mounted engines.

4. REVIEW OF LA/GTG EXAMINATION

We carried out examination of air-to-ground lateral attenuation (LA/ATG) by using data of long-term noise monitoring at Narita, from 50 selected stations located beneath and beside the straight flight route of take-off. The target of the examination period was 10 consecutive days in each of the four seasons (in total 40 days) of FY2016. Target flight route was a long section of straight ahead. Flight position of each take-off flight was investigated using received data of ADS-B. Furthermore, we classified the estimated LA/ATG values into classes of vector wind (VW) in order to examine the relationship of LA/ATG with meteorological conditions, such as 'upwind',' calm' , 'downwind'.

From the examination results in figure-4, we see that LA/ATG decreases as the elevation angle increases from 0 degrees until around 15 degrees, and that LA/ATG has a slightly negative value at middle angles of 15-65 degrees. Also, LA/ATG becomes greater as VW moves from 'downwind' to 'upwind' in the case of elevation angles lower than 15 degrees. This tendency has not changed from the previous investigation result which was the basis for the determination of 1751M. Note that all averages that do not classify VW are consistent with those of calm class.

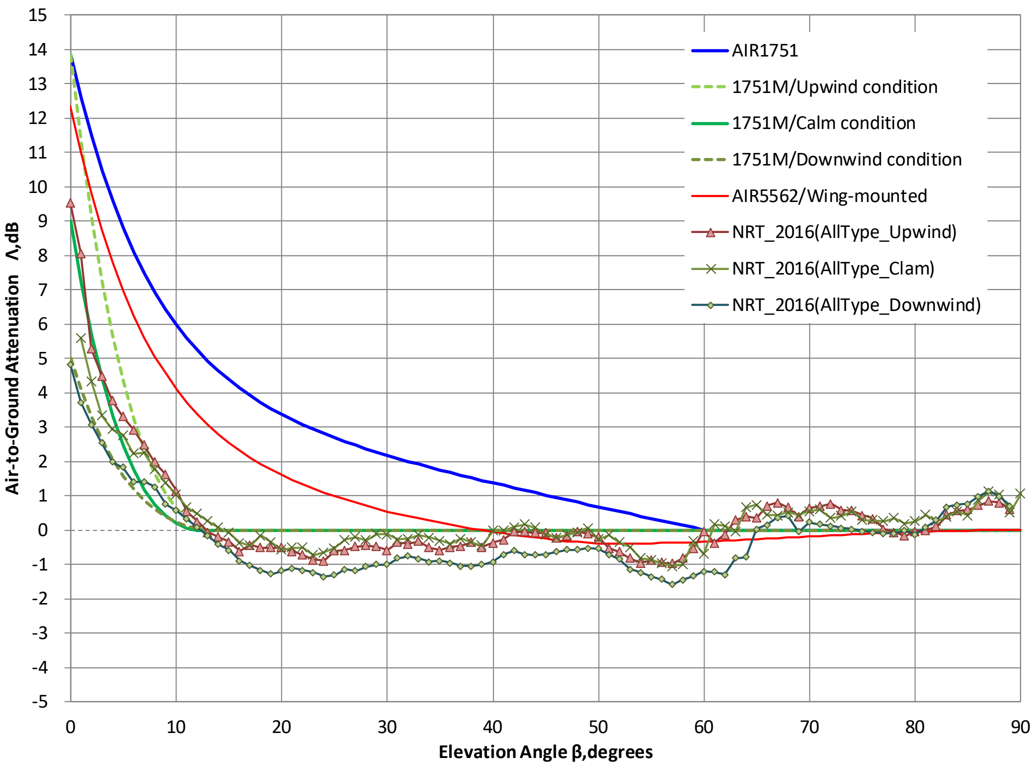

Figure 4 – Results of the average of estimated LA/ATG respectively for the three VW conditions, together with LA/ATG value from AIR 1751, 1751M (VW conditions, respectively) and AIR 5662. (Estimated LA/ATG used data of all types of aircraft).

5. VALIDATION OF NOISE PREDICTION RESULTS AMONG THREE LA EQUATIONS

From the results of the consideration so far, the focus we have to pay an attention is the elevation angle 0 degree, (i.e. the region of GTG propagation) and elevation angle 5-25 degrees. The two foci are the most remarkable differences in results of using equation of 1751M or 5662.

Thus, we examined whether the prediction results deviated from the actually observed noise data by implementation of noise predictions for a specific aircraft model and take-off weight. The prediction model was used segment model (AERC model) which we developed for adaptation to specific noise situation of Japan. Note, the AERC model substantially conforms to ICAO DOC 9911. NPD(Noise-Power-Distance) data and aircraft performance data (Distance vs Thrust, Altitude, Speed) used special data which is specialized for Narita Airport. Further, we selected the following three targets as representative for comparison and verification.

B747-400 (GE engine, medium hole distance, estimated take-off weight 600 klb)
B777-300ER (GE engine, long hole distance, estimated take-off weight 700 klb)
B767-300ER (GE engine, medium hole, estimated take-off weight 325 klb)

The actual noise measurement data for comparison with the predicted values were extracted only from agreement to target aircraft model and engine, and destinations that match the target take-off weight among the measurement results of the unattended noise monitoring station around Narita Airport. The average value of observed noise data throughout one year was used to compare to noise prediction value.

For each of the three lateral attenuation equations, using the predicted value for each monitoring station, the difference between the predicted value and the measured value was calculated, and the results were handled together with the elevation angle of from the monitoring station to the aircraft.

Figure 5 shows the comparison result, it includes all three equation's results. In the upper figure, the horizontal axis plots the elevation angle from each noise monitoring station to the aircraft, and the vertical axis plots the difference between the predicted value and the actual measured value for each noise monitoring station. The blue circle marks are expressed in difference when used equation of 1751 M, the gray circle marks are difference used AIR5662 equation, further the red circle marks also expressed the difference of AIR1751 equation. In general, the difference of predicted between measured are greatly dispersed in the low elevation angle of 30 degrees or less.

The lower figure is the result of dividing classification of GTG propagation (0 elevation angle) and every 5 degrees elevation of ATG propagation and averaging the differences of measured value and prediction value. First, at the elevation angle of 0 degree, that is, in the LA/GTG, the difference according to the 1751M equation is the smallest. When the equation AIR 5662 or the equation AIR 1751 is used, the predicted value is too small compare to measured value. It means that the value of LA/GTG of using AIR 5662 or AIR 1751 equation is too much large. In the elevation angle area of 5 to 15 degrees, the value of prediction by 1751M equation is about 4 dB too much. In other words, the 1751M equation calculates the value of LA/ATG is too small. On the other, that value of using 5662 equation roughly matches to actual measured level. In the elevation angle of greater than 30 degrees, the value of prediction by 1751M and 5662 equations show similar tendency. The prediction error also converges to approximately 0 dB. The prediction results according to the equation 1751 has been reconfirmed that underestimation at the elevation angle of 0 to 60 degrees.

Looking only at these results of figure-5, the 1751M equation needs to be corrected of increasing LA/ATG value in the elevation angle area of 5 to 15 degrees. Also, the equation AIR 5662 needs to be corrected so that LA values become smaller in the area near the elevation angle 0 degree. However, there is a difference of tendency of the discrepancy of measurement and prediction noise related in elevation angle depending on the aircraft model. Figure-6 is shows the comparison among the aircraft type for the difference between prediction and measurement according to the 1751M equation. The tendency of difference related elevation angle by B777-300ER's and B747-400's/B767-300ER's are distinctly different.

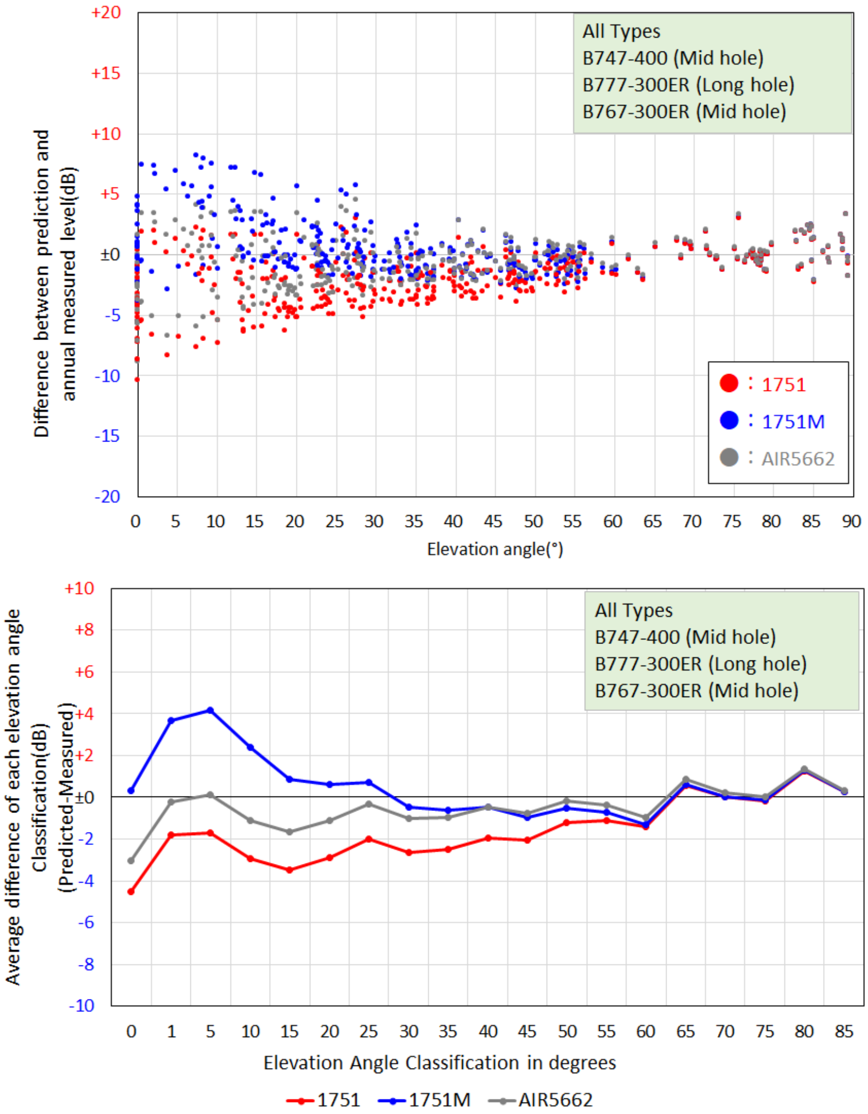

Figure-5 Prediction difference level related elevation angle comparison among lateral attenuation equations

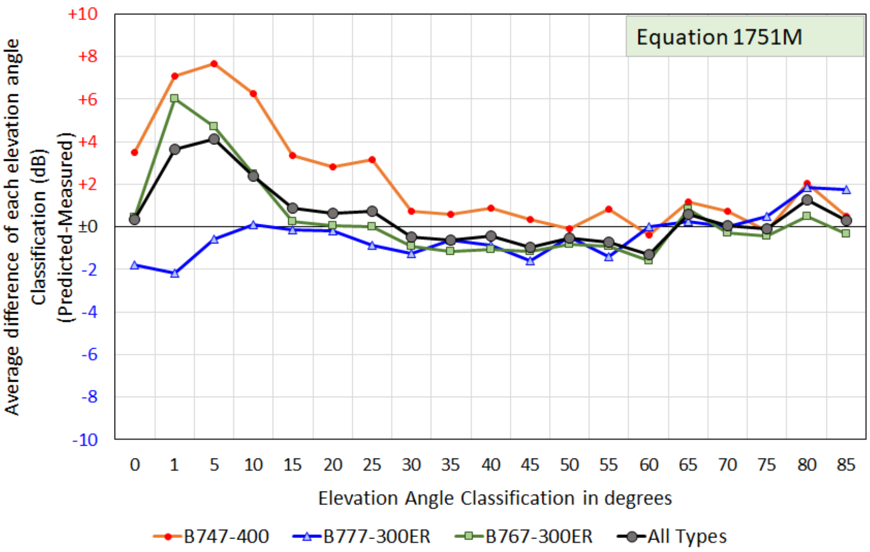

Figure-6 The average prediction difference level using 1751M equation related elevation angle comparison among various aircraft types.

6. CONCLUSIONS

This paper described the result of examination on the validity of equations for calculating lateral attenuation. There is a distinct difference in the value of LA/ATG at the area of elevation angles lower than 30° between the prediction results from lateral attenuation equations AIR 5662 and 1751M.

Thus, we examined whether the prediction results deviated from the actually observed noise data by implementation of noise predictions for a specific aircraft model and take-off weight. The prediction model was used segment model (AERC model) which we developed for adaptation to specific noise situation of Japan. We selected the three targets of B747-400, B777-300ER and B767-300ER as representative for comparison and verification. The actual noise measurement data for comparison with the predicted values were extracted only from agreement to target aircraft model, engine and take-off weight among the measurement results of the unattended noise monitoring station around Narita Airport.

Looking from the analysis results, the 1751M equation needs to be corrected of increasing LA/ATG value in the elevation angle area of 5 to 15 degrees. Also, the equation AIR 5662 needs to be corrected so that LA values become smaller in the area of the elevation angle around 0 degree.

However, there is a difference of tendency of the discrepancy of measurement and prediction noise related in elevation angle depending on the aircraft types. Therefore, the above conclusion is not clear. So, the analysis results are needed further investigation in various situation of aircraft types or airports.

7. ACKNOWLEDGEMENTS

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