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# Airport noise model taking account of soundproofing embankment and aircraft ground operation

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## ABSTRACT

When calculating noise contours, we usually take account of only fly-over noise after the start of take-off roll or before the end of engine thrust reversal after landing. In Japan, however, the national noise guideline "Environmental Quality Standard for Aircraft Noise" was revised in the end of 2008 so as to use $L_{den}$ as noise index instead of WECPNL as well as to take account of noise contributions of aircraft ground operations such as taxying, use of APU and engine run-up on the apron when noise impact of such sound sources is expected important. Over-ground sound propagation of such ground noise outward from the airport sometimes becomes the target of severe noise complaints. To prevent such aircraft ground noise from propagating outward from the airport, soundproofing embankment is sometimes constructed along the boundary of airport. This paper discusses the way of airport noise modeling which takes account of insertion loss of such embankment and noise contributions due to aircraft ground operations.

## INTRODUCTION

In a paper [1] presented in ICA 2007, a brief history of an airport noise model (JCAB Model) for calculating noise contours was introduced, but the topic at that time was confined to the prediction of noise exposure only due to aircraft fly-over noise without taking account of ground noise resulting from aircraft operations on the ground such as taxi, use of auxiliary power units (APU) on the apron, engine run-up as well as without consideration to insertion loss due to noise embankment and barriers constructed surrounding the airport. However, in a revised guideline of "Environmental Quality Standard for Aircraft Noise," notified by the Ministry of the Environment in December 2007, it has become requested to take account of ground noise in addition to flyover noise during take-off and landing in case ground noise is expected to strongly affect the sound exposure in the neighborhood of the airport.

The purpose of the Standard is to show target values for noise mitigation by the government in order to realize a comfortable sound environment widely around the airport. In general, ground noise has a negligible contribution to the cumulative noise exposure except in the proximity of the airport. Besides, it is different in noise characteristics from fly-over noise; e.g., ground noise due to APU operation usually continues very long compared to flyover noise. It is not easy to identify when it begines and how long it continues. It is usually low level compared to flyover noise, but it sometimes becomes audible or louder under specific meteorological conditions.

The generation of ground noise changes from day to day, resulting in a large fluctuation in sound exposure in the vicinity of the airport. Thus, it was not intended to be as a target sound in the evaluation of aiport noise. Nevertheless, the Ministry dared inclusion of ground noise within the scope of target sounds in case necessary to correctly evaluate sound exposure in the ploximity of the airport under pressure from local residents.

By the way, when calculating noise contours with considering noise contributions of ground noise, it is important to take account of sound shielding by contructions such as embankment and barriers. We have taken account of insertion loss by noise embankment and barriers to calculate noise contributions of takeoff ground roll and thrust reversal after landing. It must be extended to the calculation of ground noise.

## AIRCRAFT NOISE MEASUREMENT MANNUAL

In fiscal 2008, following the revision of Environmental Quality Standard, a draft new guidance material, named as Aircraft Noise Measurement and Evaluation Manual, was published for evaluation of cumulative noise exposure levels in $L_{den}$ by measurement [2].

One of difficulties in the preparation of the draft manual was how to describe the way to identify, to measure and to evaluate ground noise. At Narita International Airport, there are two independent systems of unmanned noise monitoring; one is a system that monitors flyover noise widely around the airport, whereas another is a system that mainly monitors ground noise [3]. The latter system identifies ground noise, using the information on the instantaneous 3-D sound arrival direction and a 90% percentile level over a period of one-hour or longer. However, in general, it is not easy to identify ground noise without any special means such as the information of 3-D sound arrival direction. The description in the draft manual is now limited to a primitive way to detect it. The ministry is now asking local governments apply the draft manual to actual noise exposure evaluation by measurement at several airports, and afterwards it plans to revise the draft manual if need be for publishing by the enforcement of the new guideline in April, 2013.

## PAST EXPERIENCE IN NOISE MODELING CONSIDERING BANK AND GROUND NOISE

In Japan, there are two laws on noise measures around civil airports. One is a law for remedial subsidy programs (Aircraft Noise Preveosion Law; ANPL) to mitigate noise impact around the airport. Another is a special act for prevension of aircraft noise damage beforehand (Special Act for Preventing Noise damage; SAPN).

Based on the law ANPL, various remedial measures have been executed; house removal and soundproofing of houses in order to recover a quiet living environment around the airport. Noise zones for application to remedial measures have been determined, based on noise contours calculated using the JCAB model. Note that it is planned to calculate noise contours using $L_{\mathrm{den}}$ as noise index, instead of WECPNL, from fiscal 2013.

The special act, SAPN, was established to prevent urbanization of rural environs around the airport at Narita International Airport; building houses in a noise zone (WECPNL>80dB) are always prohibited, whereas building houses without treatment of sufficient soundproofing are also prohibited in another noise zone (WECPNL>75dB). These zones are determined, based on noise contours calculated by the JCAB Model together with adjustment for insertion loss of embankment in order to attain a higher precision than that required for application to ANPL, because SAPN restricts private right of residents on land use. At Narita, a long-range plan of embankment and afforestation has been propelled so that local communities around the airport, especially on the side of runway can recover a quiet and comfortable living environment. Embankment is expected to realize noise reduction at least 10dB behind the bank. Therefore, it has been important to take account of insertion loss by the embankment when calculating noise contours for the determination of noise zones by the special act. The basic idea is to replace the embankment by a finite-length thin barrier and to calculate insertion loss of the barrier using a theoretical equation based on Maekawa Chart [4-7]. We have used it after we examined the validity of the equation by field experiment actually at the embankment [8-9].

Another case we took account of ground noise is a noise model for heliports. When air transportation by helicopter seemed to show a rapid increase in late eighties in Japan, noise impact around heliports became a matter of special concern, although complaints against helicopter noise had been brought from residents around heliports. With this as a turning point, evaluation of helicopter noise and mitigation measures had been taken up as an important subject for discussion. However, the Environmental Quality Standard did not apply to most heliports, because there were a rather small number of flight movements a day at a greater part of heliports. Thus, a provisional guideline for preservation of acoustical environments around small airports including heliports was notified to complement the Environmental Quality Standard, in which it was specified to make noise evaluation using $L_{\mathrm{den}}$, and a helicopter noise model was developed to calculate noise contours using $L_{\mathrm{den}}$ around the heliport [10]. Helicopters usually perform idling over a very long time period as well as make exercise to hover in the air. Many heliports are narrow and are located close to neighboring people. Thus, we cannot make a correct noise prediction without taking into account idling and hovering. Thus, our heliport noise model could take account of noise contributions from helicopter operations on and near the ground. To our regret, the heliport noise model became almost forgotten as the registration of helicopters rapidly decreased at the end of bubble economy in Japan.

## NOISE MODEL WITH CONSIDERING SOUND SHIELDING BY EMBANKMENT

As stated in the previous section, when we calculated WECPNL contours to determine noise zones for the special act SAPN, we used a procedure to calculate sound shielding by the embankment as insertion loss $\Delta L_{\mathrm{dif,fb}}$, by replacing the embankment with a finite-length thin barrier [4-5]. The insertion loss was calculated as a combination of noise attenuation values of four imaginary hemi-infinite barriers, using the following equation (See Figure 1).

$$\begin{aligned}\Delta L_{\mathrm{dif,fb}} &= \Delta_{1-5} - \Delta_{0-5} \\ &= 10\cdot\log_{10}\{10^{\Delta_{123}/10} \\ &\quad + \left(10^{\Delta_{0-5}/10} - 10^{\Delta_{123}/10}\right) \\ &\quad \cdot (10^{\Delta_{146}/10} + 10^{\Delta_{358}/10})\} - \Delta_{0-5}\end{aligned} \tag{1}$$

Here, $\Delta L_{\mathrm{ijk}}$ means an insertion loss when sectors other than $\Gamma_i$, $\Gamma_j$, $\Gamma_k$ are assumed to be an infinite thin barrier.

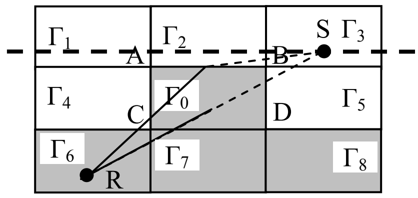


Figure 1. The way of space division to calculate insertion loss of a finite-length thin barrier [4, 5]. S: Source, R: Receiver, A/B/C/D: barrier, and$\Gamma_i$, i=1,,8; space.

Figure 2 shows result of a comparison of $L_{\mathrm{ASmax}}$ between measurements (marks) and calculations (solid lines). The experiment was carried out around an actual embankment at Narita Airport [9]. On the other, in general, sound shielding by embankment/barriers changes dependent on the geometry as well as on the frequency. The main part of frequency components of aircraft noise observed behind the bank lay in 250-500Hz octave bands, and we made the calculation at a frequency of 250Hz. We also assumed that the height of receivers was 1.2m above ground and that the sound source was raised 4m higher by assuming the sound source as aircraft engines of B747. In Fig.2, (a) shows result at various points 600m distant from the runway and (b) result at various distances along lines perpendicular to the runway (i.e. lines C, D and N). Note thatdistance between the embankment and the runway was 500m. These results seem to prove the validity of the calculation, because the measurements almost coincide with the calculations. Looking at these results, the insertion loss rapidly fades away outside the bank edge. Based on these results, we modified the JCAB (WECPNL) model to determine a closest bank to each observation point and calculate its insertion loss using the geometry among the bank, source and observer.

In case we calculate WECPNL contours, however, we only need to assume that the section, on which the sound source and the receiver are placed, is located at a place where the distance between the sound source and the receiver becomes the minimum. However, in case we calculate $L_{\mathrm{den}}$ contours, we have to repeat the calculation of insertion loss by changing the location of the sound source along the flight path. Fortunately, it is expected that embankment contributes to

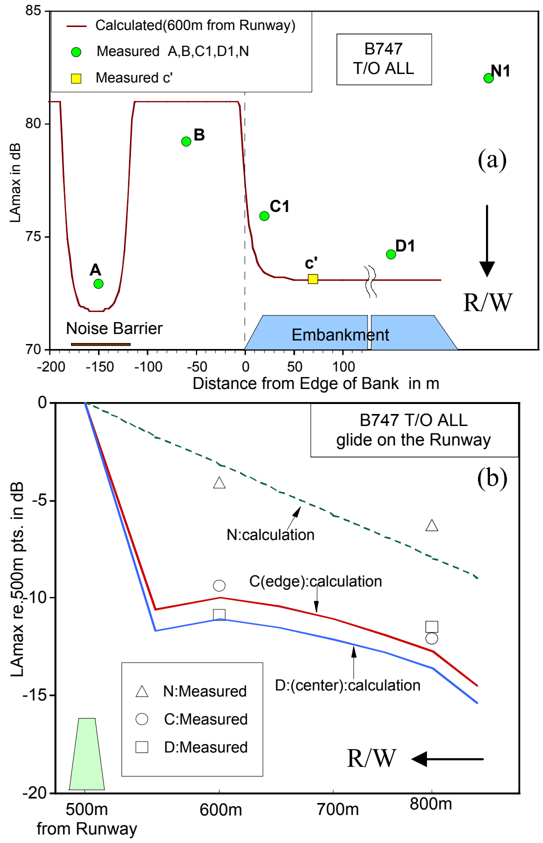


Figure 2. Comparison of $L_{ASmax}$ between measurements and calculations with and without bank/barrier insertion loss; (a) comparison at various points on a line at a distance of 600m from the runway, and (b) comparison at various distances along lines perpendicular to the runway [9].

sound insulation only when the aircraft rolls on the ground or lift off the ground.

Finally, the assumption of a finite-length thin barrier seems to fit to field measurements, but some research [5, 11] pointed out that insertion loss of a thick embankment becomes a bit lower than that of a thin barrier. In such cases, as is shown in Fig.3, insertion loss can be evaluated by considering double diffraction at the edges X and Y dependent on the geometry , i.e., dependent on the receiver location (I~III). Of course, the situation will change if the sound source is raised higher than the bank.

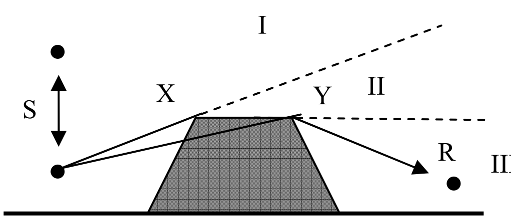


Figure 3. The way of space division to calculate insertion loss of a thick embankment [4, 5]. S: Source, R: Receiver, and I~III; space regions.

## NOISE MODEL WITH CONSIDERING GROUND NOISE CONTRIBUTIONS

As stated before, when air transportation by helicopter seemed to show a rapid increase in late eighties in Japan, the Office of Noise Abatement Technology, Civil Aviation Bureau had no adequate means to assess noise impact around heliports. Helicopters get lift and thrust power by rotating rotors. It causes great difference in flight procedures and in noise characteristics from fixed-wing aircraft. In 1988, the Office asked Airport Environment Improvement Foundation to organize a committee for developing a prediction model of helicopter noise around heliports. By the time, the Environment Agency (the current Ministry of the Environment) notified a provisional guideline for preserving environmental quality around small airports including heliports in 1990.

The committee decided to develop a new prediction model using $L_{AE}$ and $L_{den}$ according to the guideline and made a pilot program. Note that this program is the origin of the new JCAB Model using $L_{den}$ [13-15]. WECPNL cannot evaluate effects of long lasting noise due to hover/idle in heliports, for it is calculated from maximum A-weighted sound pressure levels. The methodology of prediction was established following the way of FAA models (HNM and INM), but there were differences between USA and Japan, not only in the status of helicopter and heliport operations, but also in the opinion of applying a prediction model. HNM was developed as a technical means provided to local authorities, heliport planners and so on, while Japan model was intended for the exclusive use of JCAB to perform land use planning around heliports.

In the pilot program, the prediction algorithm, which followed the way of HNM, was based on the calculation of noise exposure brought about due to a series of flight oerations, called as Single Operation (SO), e.g. “start of engine roll at a heli pad till fly-away to somewhere,” “approach from somewhere till engine stop at apron,” and so on. Each SO consists of many segments such as fly-over, taxi and static operation. A special operation that starts at apron, moves to a helipad, stays there, goes back and stops at apron was also permissible. Noise exposure of a SO was calculated from an energy sum of noise contributions from all segments included in the SO. The contribution of a segment could be calculated from noise-distance database with adjustments for left/right directivity, effects of finite-length segments and source noise corrections. Although HNM assumes a dipole model on the directivity of sound sources when calculating the contribution of a finite-length segment, our field measurements showed that the directivity pattern during flight differs from the dipole model according to the type and flight mode of helicopter, but modification of the directivity pattern did not improve the precision of prediction so much. The effectiveness of the pilot program was checked several times; predictions were compared with noise measurements near a heliport, resulting in maximum errors of 3~5dB on sound exposure levels [10].

## ISSUES TO BE DISCUSSED

There are several issues when applying these procedures for considering sound shielding of embankment and contributions of ground noise to $L_{den}$ model. Up to now, it is not easy to evaluate contributions of ground noise as precise as fly-over noise, because of limited knowledge and information necessary for calculation of sound exposure due to ground noise.

First is how to set up noise-distance database for these special aircraft operations such as taxi, APU operation and thrust reversal. As a temporary means for the time being, we may use database for usual take-off and landing as a substitute for those special operations.

Next is the sound source directivity, which seems to be different among various tpes of aircraft even in case taxying. It may be important if we consider turns of aircraft at the runway end. Aircraft sometimes holds at the end of runway to wait for take-off. APU may be used every where within the apron. It is necessary to get information on the records of APU operations round the year.

The way of executing thrust reversal changes between “high” and “idle” dependent on various reasons, and thus it is necessary to get information on the rate of incidence to execute thrust reversal for individual aircraft types, airline company and seasons/weather conditons. Besides, meteorological conditions strongly affect outdoor sound propagation over ground. It is also very important how to evaluate the long-term average sound exposure around the airport [16-17].

## CONCLUDING REMARKS

In Japan, the national noise guideline “Environmental Quality Standard for Aircraft Noise” was revised in the end of 2008 so as to use $L_{\mathrm{den}}$ as noise index instead of WECPNL as well as to take account of noise contributions of aircraft ground operations such as taxi, use of APU and engine run-up on the apron in case noise impact of such sound sources is expected important. It is planned to calculate $L_{\mathrm{den}}$ contours from fiscal 2013. In such cases, sound attenuation by noise banks and/or barriers is important for a precise calculation. Thus, this paper discussed the way of airport noise modelling taking account of effects of noise embankment and aircraft ground operations, based on our past experiences in which we took account of those factors in the calculation of WECPNL contours.

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