Practical method of considering effects of terrain and building structures on sound propagation

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ABSTRACT

This paper discusses practical methods of calculating adjustments for sound insertion loss due to terrain/building structures in airport noise modelling. The Japanese revised noise guideline "Environment Quality Standard for Aircraft Noise," requires sound exposure evaluation of aircraft ground activities like taxiing and using APU. This paper first makes a brief review of technical aspects of developing airport noise modeling in Japan, secondly describes the way of considering aircraft ground operation noise, thirdly discusses practical ways of calculating adjustments for sound insertion loss due to terrain/building structures and excess ground attenuation, and finally it discusses future issues. It also refers to examination of the validity of such practical ways by applying numerical calculation as well as by measurement.

Keywords: Aircraft noise, Modeling, Ground noise I-INCE Classification of Subjects Number: 52.2

1. INTRODUCTION

In Japan, a revised noise guideline "Environmental Quality Standard for Aircraft Noise" (EQSAN), enforced in April 2013, requires taking account of noise contributions due to aircraft ground operations, which we call ground noise in the following, such as taxi, engine run-up and operation of auxiliary power unit (APU), if necessary for appropriate noise impact assessment when evaluating aircraft noise exposure around the airport (1). This requirement applies to predictive modeling of airport noise also (2), although the target of noise prediction had been focused to noise of flyover movements in the conventional noise modeling because flyover noise overwhelmed ground noise except in the vicinity of the airport as well as computational capacity was limited and was fully occupied with calculation of noise contributions due to flyover movements. Besides, there was no information on ground noise and no available procedures to calculate contributions of such noise. However, in the meantime, it has become no longer appropriate to ignore it as a result of drastic decrease in sound exposure due to flyover movements. Now, people sometimes complain about suffering impact of ground noise under special conditions on terrain and building structures as well as under certain meteorological conditions. The revised guideline came to require evaluation of ground noise, if necessary, to respond to such needs. Computational performance has improved dramatically and enormous computing burden has become not bother. However, it is necessary for the evaluation of ground noise to establish calculation procedures, prepare necessary data on sound source characteristics and operational performances and take into account influences of structures and terrains intervening the sound source and receivers on sound propagation in order to accurately evaluate sound propagation over ground.

This paper makes a brief review of calculation algorism in airport noise modeling in Japan, describes the way of considering noise contributions of aircraft ground operations and procedures to calculate sound shielding effects of buildings and terrains intervening between the sound source and receivers in order to revise the noise prediction model in response to the requirement of the revised noise guideline. It also discusses simplified practical procedures to treat actual complex situation as well as future topics like examination of the validity of practical procedures and further improvement to consider sound shieling effects of building structures and terrain, the way of preparing terrain and buildings data, simplification of such complicated procedures with the aid of harmonized use of noise simulation techniques.

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2. REVIEW OF CALCULATION MODELS FOR AIRPORT NOISE IN JAPAN

The development of airport noise model in Japan goes back to early 1970s, as reported in previous papers (2, 3). The Civil Aviation Bureau of Japan (JCAB) and Aviation Environment Research Center (AERC) studied modeling methodology of airport noise, referring to an old FAA model (4, 5), and established an initial version of the Japanese airport noise model JCAB-1. This model calculating noise contours, using $WECPNL_J$ as noise index and targeting noise contributions of only flyover movements, was used as the basis for remedial subsidy programs of the government to mitigate noise impact around airports under the Aircraft Noise Prevention Law. The model has been revised several times concerning adjustments for excess ground attenuation (EGA), flight track dispersion, etc., resulting in realization of high precision in noise prediction.

Next step was the development of a heliport noise model using L_{den} as noise index in early 1990s. There was an indication that air transportation by helicopter was going to increase rapidly in Japan. It was anticipated that impact of helicopter noise would become a matter of special concern, but most heliports were out of application of EQSAN, because the number of flyover movements per day was smaller than the limit of application. Thus, in the late 1980s, a provisional noise guideline was notified for such small airfields including heliports by the Ministry of the Environment, and afterwards a noise model using L_{den} was developed to calculate noise contours for heliports by JCAB and AERC (6). It was considered not appropriate to assess helicopter noise using $WECPNL_J$, which is defined using L_{ASmax} with a correction for weighted number of noise observations per day. Differently from fixed-wing aircraft, helicopters perform special flight operations like hovering in the air, hover/air taxi, vertical ascent and descent near the ground as well as engine idling on the ground over a long period of time. It was necessary to take into account such noise contributions, which were dealt with separately from usual take-off and landing operations.

Around the same time, a procedure taking account of sound shielding of noise embankment by calculating sound insertion loss of a finite-length thin barrier (7) was introduced into JCAB-1. More precise determination of noise zones was required for restriction of private right of residents on land use under the Special Act for Preventing Noise Damage. Result of field experiment proved that sound shielding by an embankment brought sound insertion loss of about 10dB behind the embankment (8, 9). Note that this act was enacted to prevent urbanization of rural environment around Narita International Airport and that long-range plan of constructing noise embankment and afforestation had been propelled in the surrounding of the airport so that local community in the side of runway could preserve a quiet and comfortable living environment.

Developing a new energy-based airport noise model, which was expected to succeed JCAB-1, using noise metrics like L_{den} was started since 2001. It was discussed whether we should employ an existing model like INM to save cost and with an emphasis on international consistency of prediction methodology, or whether we should develop our own model to utilize knowledge and know-how accumulated since the days of $WECPNL_J$ model and with an emphasis on the continuity of conditions for calculation of noise contours. Finally, it was decided to develop our own model. The heliport noise model stated above was used as the basis for the new model, which was designed to consist of three parts of front-end, calculation engine and database and to realize easy manipulation for users like tracing a flowchart. An initial version of the new model was completed in 2004 as an AERC Model (10). Noise-Power-Distance Data were prepared by approximation of L_{AE} by L_{Asmax} with an adjustment for event duration. However, at that time, it was not expected to include contributions of ground noise into the model. Nevertheless, we had to revise the model to consider ground noise when EQSAN was revised in 2007. Finally, a revised model was completed to take into account noise of ground operations as well as to calculate sound shielding effect of noise embankment by applying an equation of thin and finite-length noise barrier in 2009. In 2008, the model was also revised to include an option to select a procedure to divide the initial ground roll segment and interpolation of engine power to meet with requirements of ECAC Doc. 29 (11). Finally, the model was finished as a national model JCAB-2 for JCAB in 2011-2013. Database of NPD and Performance Data, necessary for calculation of L_{den} contours at most domestic airports in Japan, are ready for flyover noise of most major aircraft types and modes (take-off & landing) and for ground operation noise of several typical types of aircraft and modes (taxi, APU & engine run-up). It is also able to calculate sound shielding effect of thick structures like embankment and terminal buildings.

A brief review was made about the situation in consideration to noise of aircraft ground activities in airport noise models in foreign countries. According to a report in 2009, US considers taking into account noise during taxi in INM (12). It says that taxi may contribute to an increase of 1.5dB in L_{dn}. EU has been engaged in making noise maps for all transportation modes and now uses an airport noise model CNOSSOS, which seems to place importance on noise contributions of engine run-up on the ground and considers a possibility to include it in future (13). There was no reference to noise of tax and APU operations. In Germany a revision was made for the document AzB specifying the procedure for calculation of airport noise to require consideration to noise contribution of taxi operations (14, 15), but details are unknown yet. There is another paper that reported sound source characteristics necessary for consideration to taxi noise (16).

3. THE WAY OF DEALING WITH GROUND NOISE IN JCAB-2

3.1 Situation of Ground Noise

Aircraft noise observed in the vicinity of the airport, especially in the side of runway, includes flyover noise and ground noise due to aircraft ground operations of taxi, APU operations and engine run-up. Taxi noise is observed as single event sound similar to flyover noise, whereas noise of APU and run-up is observed as stationary sound. Noise calculation of the conventional model focused on flyover noise, because flyover noise overwhelmed ground noise except in the proximity of the airport. Note that flyover includes aircraft roll on the runway both after the start of take-off roll and till the end of thrust reversal after landing. On the other hand, considering ground noise means inclusion of noise due to aircraft ground operations within the target of noise calculation. In the revised EQSAN, limitation on airfields that applies based on the minimum number of movements per day was deleted, and many heliports and small airfields became target airports. It means that noise models must be able to calculate noise contours around heliports, resulting in needs to consider special characteristics of helicopter noise and operations: Helicopters make a lot of special flight operations like vertical ascent & descent, hover/air taxi as well as stationary operations of hovering and long engine idling. The sound source characteristics are also different from fixed-wing aircraft.

Ground noise is different from flyover noise in many aspects. APU and engine run-up radiate long-lasting stationary sound. APU operation noise observed near the apron or on the side of runway is usually low-level compared to aircraft flyover noise and is easily indistinguishable from ambient noise. It is not easy to identify when it begins and how long it continues, even in case of attended noise measurement. Engine run-up is usually performed late in the night, but sometimes in the day time. The thrust power of engine is switched from idle to climb or up to take-off, and run-up continues very long. If run-up is performed in special facilities treated for noise reduction, sound immission in the surrounding area remains small, whereas if it is performed on an open ground without noise suppressor sound immission becomes quite large. Taxi usually causes single event noise, similar to flyover. However, taxi noise may be long-lasting stationary sound when a lot of aircraft line up and wait in a row for take-off on the taxiway, whereas it may become intense tonal sound due to the directivity of fan sound near a bent on the taxiway.

3.2 Necessary Information and Treatment

The L_{den} model JCAB-2 was constructed in the template of the heliport noise model. JCAB-2 is able to take into account contributions of ground noise due to taxi, APU and run-up. The procedure to consider ground noise was also constructed following the way that the heliport noise model deals with special flight operations like hovering and idling, separately from usual take-off and landing. Necessary information for considering taxi noise is the same as that for flyover noise: noise-distance data, performance data as well as information on taxi route and operational performances. On the other, necessary information for considering noise due to stationary sound sources like APU and run-up includes noise-distance data, the sound source directivity as well as operational performances. When the sound source stays on and/or near the ground, it becomes important to consider sound shielding by terrain and structures like terminal buildings, barriers and embankment. It is important how to get information on the distribution of terrain and structures as well as acoustic characteristics of their surfaces.

Taxi is treated as a kind of flyover consisting of only ground roll between runway ends and terminal spots on the apron before take-off or after landing. Differently from usual take-off and landing, taxi has both start and end points, but it has no scatter in flight track. Taxi for take-off starts on the apron after it is pushed back from the spot. Engines are started to run in turn during the pushback, but it is kept almost in idle condition except the start of taxi. On the other, taxi after landing starts when aircraft leaves the runway and ends when it stops on a spot. Noise-distance data for taxi mode has been established up to now from frequency spectra and sound source directivity characteristics calculated using noise measurements carried out on the side of taxiway, but it can be substituted with noise-distance data for flyover noise. Considering the consistency between taxi and usual flyover modes of fixed-wing aircraft, we set the height of the sound source for taxi to zero, i.e., ground level, but we use an actual height for hover/air taxi of helicopters when calculating sound exposure. Concerning calculation of segment correction that accounts for the finite length of a segment we use the same equations as usual take-off and landing. Note that taxi noise may be sometimes long-lasting stationary sound when aircraft line up and wait in a row near the end of runway for waiting take-off, whereas traffic congestion occurs and taxi speed changes in crowded airports, but there are no sufficient data necessary for consideration of such situation in the model.

Auxiliary Power Unit (APU), installed in the fuselage, runs to supply power to the parked aircraft. It starts soon after aircraft stops at a spot and stops when engines start after aircraft push back. APU is a fixed stationary and directional sound source. The position of intake and exhaust vent for APU is different for each aircraft model, resulting in difference in sound source directivity. Sound power changes dependent on the situation whether it supplies power for air conditioning. Thus, we prepared two sets of noise-distance data (low and high powers) and two sets of sound source directivity data (horizontal and vertical distributions) for each aircraft model. The horizontal sound source directivity is expressed in circumferential level difference in A-weighted sound pressure level re. 90 degrees clockwise from the direction of aircraft nose at a specified distance (e.g., 1km) from the center of aircraft. Calculation of sound exposure due to APU operation from sound power spectrum and the sound source directivity with adjustments for spherical spreading and air absorption may be superior, but it is too much time-consuming.

Run-up can be treated as a stationary sound source, the same as APU. In case of fixed-wing aircraft equipped with multiple engines, thrust power is set to a different value for individual engines during actual run-up operation, resulting in asymmetric directivity characteristics on the left and right sides of the fuselage, but we usually set it as symmetrical on both sides of the fuselage and prepare noise-distance data for three categories of thrust conditions: idle, part-power and full-power. If engine run-up is performed in special facilities, we set a directivity pattern different from that for open ground conditions. On the other hand, helicopters perform idling on the ground as well as hovering in the air: noise-distance data are prepared for two categories of ground idle and flight idle and for two categories of hover in ground effect and hover without ground effect.

4. PRACTICAL WAY TO CONSIDER EFFECTS OF STRUCTURES AND TERRAIN

Sound shielding by an obstruction when an aircraft stays on or near the ground is considered using a procedure to calculate sound insertion loss of a finite-length thin barrier or a thick rectangular structure like embankment and terminal building in JCAB-2. Necessary equations were established referring to a guidance material of noise prediction model 2008 for road traffic noise, published by the Acoustical Society of Japan (17).

When calculating sound insertion loss of an obstruction, we must practically specify a location of the sound source for each segment of a path. In general it is assumed to be at the midpoint of the segment. If a segment is longer than 100m, it is divided into several segments of 100m or shorter. If the obstruction intervening between the sound source and a receiver is a thin barrier, sound shielding is calculated as sound insertion loss of a finite length thin barrier, whereas in case of an obstruction like a rectangular building or embankment, it is replaced with two imaginary thin barriers closely located each other at the two shoulder edges of the obstruction. Sound insertion loss is calculated for either of the two imaginary barriers, selected dependent on the geometrical relationship among the source, the receiver and the obstruction. Sound insertion loss for a thick obstruction becomes a bit smaller than that for a thin barrier, which can be confirmed valid if we look at the result of field experiment at Narita (9, 10). Note that in the original procedure developed for application to road traffic noise the height of the sound source is fixed and the receiver height is assumed as arbitrary. When applying to aircraft noise, we replaced the role. Note also that our procedure ignores both oblique sound propagation over the obstruction and the difference in sectional shape of the obstruction between embankment and rectangular parallelepiped, following the reference. Sound reflection from a structure is also ignored if a receiver is located between the sound source and the structure. In case multiple structures are connected each other, we ignore the contribution of sound bypassing the connected side of the structures. We also ignore sound shielding if the receiver is located on the top of a structure.

By the way, a few procedures calculating EGA adjustment are incorporated in JCAB-2 and all those assume that the ground is flat, which is incompatible with the existence of an obstruction. Ignoring either of sound insertion loss and EGA may result in overestimation in level calculation, and thus it is necessary to consider both of the two adjustments. In JCAB-2, two ways of practical treatment are now available: one way is to calculate EGA over flat ground without obstruction, and another is to locate an imaginary intermediate point on the top of the structure, calculate EGA values for both sides of the structure and sum up those, although the validity of these practical ways are not yet examined.

Airport noise model for calculating noise contours usually assumes flat ground, but it is sometimes inevitable to suppose the ground uneven. Some airports are constructed on a hill and residences lie on the plane. In other cases, terrain on the side of the airport is a hill or a valley. Considering contributions of both flyover noise and ground noise over such uneven ground inevitably requires taking into account effects of terrain conditions on sound propagation. In JCAB-2, two provisional ways of treatment are prepared. One is to specify height difference of a specified land area around the airport so that the land is elevated or depressed, whereas another is to use built-in information on terrain conditions, based on digital maps of Geospatial Information Authority of Japan, around a specified airport. Up to now, however, this information is used only for correction of slant distance from the receiver to the sound source. If we want to apply it to precise evaluation of sound propagation over terrain and structures, we must solve the issue of compatibility with the current methodologies of JCAB-2 dealing with sound scatter, EGA and sound shielding, which all assume flat ground.

5. FUTURE ISSUES

Within and around the airport, there are many structures that shield or refract sound radiated from aircraft flyover and ground operations: terminal buildings and hangars, embankment and barriers and a lot of houses and buildings. Some structures are independent, while others are lined or connected each other. Noise prediction by segment model is originally intended to evaluate long-term average sound exposure, being based on simplification and using empirical adjustment equations. Thus, inclusion of detailed description on sound situation in the proximity of the airport does not match the original policy, nor it may contribute to increase in noise precision. Thus, it is suggested that when considering sound shielding of structures, application should be limited to large structures such as terminal buildings, hangers and embankment, which are located within and at the border of the airport and significantly affect the situation of sound exposure widely around the airport. Ignoring houses and other structures existing in the sound receiving area causes omission of sound attenuation in terms of shielding and contributes to higher sound exposure calculations. But, it causes neglecting sound scatter and multiple reflections simultaneously, and it may offset the attenuation. Considering details may not always brings improved precision in noise prediction.

JCAB-2 is constructed to be able to take into account frequency spectrum and directivity characteristics of the sound source when calculating noise contributions of aircraft ground operations on or near the ground, but preparing necessary data for calculation is not yet sufficiently ready. Three ways of considering the source frequency spectrum are now available in JCAB-2: 1) Use the same typical frequency band for the calculation of sound insertion loss irrespective of propagation distance, 2) specify a typical frequency band dependent on distance and select individual frequency bands, and 3) calculate sound insertion loss for each band and sum up all contributions. The first method supposes that all important target regions for noise exposure evaluation are located very distant from the sound source regions, i.e., from the airport. The second and the third assume that target regions are distributed in wide area from close to distant from the sound source regions. In addition, we cannot consider effects of acoustic properties of the surface of structures, sound reflection and scatter from multiple structures located along the sound propagation path and in the sound receiving region on sound exposure calculation. However, it is not yet examined whether such detailed treatments are really necessary. It may be too much detailed: there are many problems not yet solved like compatibility of calculation methods of EGA, sound shielding and effects of terrain conditions. Sound propagation over ground is strongly affected by meteorological conditions. Mutual influence of meteorological effects with those of terrain and structures is also a major challenge. We are now under investigation of such issues using analytical means like FDTD, PE and BEM together with actual noise measurements. Heights of the sound source and receiver points were ignored in the calculation of sound exposure due to flyover noise, but those become important in the calculation of noise contributions of aircraft ground operations. Matching those is also an important issue for improving precision of noise calculation.

6. CONCLUDING REMARKS

This paper made a brief review of technical aspects of developing airport noise modeling in Japan, described the way of considering noise of aircraft ground operations, and finally discussed practical ways of calculating adjustments for sound insertion loss due to terrain/building structures and excess ground attenuation. It also referred to examination of the validity of such practical ways by applying numerical calculation as well as by measurement. Comparison of calculations with result of unattended noise monitoring suggests that the validity of the current L_{den} model is the same as WECPNL model except the vicinity of the airport, where noise of aircraft ground operations contributes to cumulative sound exposure level. It is expected to realize the same level of accuracy in calculation also in the vicinity of the airport, and it is now expected to make examination on the practical algorism for calculating simultaneous effects of EGA and sound shielding of terrain and structures. Finally, load of calculations has become more than doubled by the consideration of noise contributions of aircraft ground operations. It requires developing efficient calculation procedures based on the introduction of recent technologies like parallel computing in case of noise contour calculation around major airports.

REFERENCES

1. Takemoto K, Shishime T, Yamashita Y, Tanaka R, Murahashi T. Noise Evaluation in Japan. Proc. INTER-NOISE 2007.
2. Yamada I. Recent progress in development of airport noise models in Japan. Proc. ICA 2007.
3. Yamada I. Recent progress in airport noise modeling taking account of noise due to aircraft ground activities in Japan. Proc. INTER-NOISE 2013.
4. Igarashi J, Ishii Y, Yamada I. Computation and drawing of aircraft noise exposure forecast contour with the aid of mini-computer. Report of the Inst. Space and Aeronautical Science 6, No.2 C. 1973. p. 606-625.
5. Yoshioka H. Evaluation and prediction of airport noise in Japan. J. A. S. Jpn. (E) 21, No.6. 2000.
6. Yoshioka H, Wakuri T, Tokita Y, Yamada I. Basic consideration for developing a helicopter noise prediction model, Proc. INTER-NOISE 94.
7. Yamamoto K, Hotta R, Takagi K. A method for the calculation of noise attenuation by finite length barrier. J. A. S. Jpn. 50 (4). 1994.
8. Shinohara N, Saito H, Yamada I. Examination of Effectiveness of Afforestation and Embankment for Noise Abatement in the Sidelines of Airport. Proc. INTER-NOISE 95.
9. Shinohara N, Saito H, Yamada I. Measurement of noise propagation at the edge of a soundproofing embankment and its comparison with an airport noise prediction model. Proc. INTER-NOISE 98.
10. Yoshioka H, Iwasaki K, Yamada I. Recent Development on Energy-Based Aircraft Noise Modeling in Japan. Proc. ICA 2004.
11. ECAC Doc.29: Report on Standard Method of Computing Noise Contours around Civil Airports. Volume 2: Technical Guide. EUROPEAN CIVIL CONFERENCE EUROPEENNE, AVIATION CONFERENCE DE L’AVIATION CIVILE. 07/12/2005.
12. Page J, Bassarab K. R., Hobbs C. M., Robinson D. H., Schultz T. D., Sharp B. H., Usdrowski S. M., Lucic P. ACRP Web-only document 9: Enhanced Modeling of Aircraft Taxiway Noise – Scoping. Final Report for ACRP (Airport Cooperative Research Program). Project 11-02 Task 08, USA. 2009.
13. EC, Common noise assessment methods in Europe (CNOSSOS-EU), JRC Reference reports. 2012.
14. Isermann U. Overview on the development of the airport noise modeling standard DIN 45689. Proc. INTER-NOISE 2011.
15. Myck T, Vogelsang B. A proposal for a European aircraft noise calculation procedure. DAGA 2009.
16. Asensio C, Pavon I, Ruiz M, Pagan R, Recuero M. Aircrafts’ taxi noise. Sound power level and directivity frequency band results. Applied Acoustics. 70. 2009.
17. The Research Committee on Road Traffic Noise in the Acoustical Society of Japan. ASJ Prediction Model 2008 for Road Traffic Noise: Report from the Research Committee on Road Traffic Noise in the Acoustical Society of Japan. J. A. S. Jpn. 65, 4. 2009.