Validity of the method of estimating long-term average cumulative aircraft noise exposure based on repetitive short-term noise measurements

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ABSTRACT

This paper discusses the validity of methods of estimating long-term average cumulative aircraft noise exposure, measured in $L_{den}$ around the airport. Last year, Ministry of the Environment, Japanese Government, notified a revised guideline of "Environmental Quality Standard for aircraft noise," in which noise index for evaluating aircraft noise was changed from WECPNL to $L_{den}$. Now, in the guideline, it is requested to estimate annual average cumulative noise exposure around the airport, being based on repetitive short-term noise measurements, but the validity has not been examined up to now. Thus, taking this opportunity, we investigated whether it is valid to estimate annual average cumulative noise exposure at various sites around airports using results of repetitive short-term noise measurements. First, this presentation gives a brief summary of the revision of the standard. Secondly, it discusses the variability in the estimations of long-term average cumulative noise exposure calculated from repetitive short-term noise measurements with regards to the measurement time period. It was confirmed that in case of civil airports power average of one-week measurements repeated seasonally twice or four times a year makes it possible to get a good estimation of annual average cumulative noise exposure. Finally, it also discusses effective ways we estimate single event noise exposure, measured in sound exposure level or maximum sound pressure level, under various environmental noise situations around airports.

1 INTRODUCTION

In December, last year, the Ministry of the Environment of Japanese Government notified a revised guideline of "Environmental Quality Standard for Aircraft Noise (EQSAN)," in which noise index for evaluation of cumulative noise exposure levels around airports was changed from WECPNL to $L_{den}$ \cite{1}. It took more than thirty years after the movement toward $L_{Aeq}$ metrics for evaluation of environmental noise had begun to appear early 1980s in Japan \cite{2}. The movement was unexpectedly prompted by a dispute over a slight contradiction found in the determination of cumulative noise exposure levels in WECPNL when an interim parallel runway opened to use at Narita International Airport; WECPNL values calculated from noise measurements of all aircraft movements using both the main and the parallel
runways happened to be a little lower than those for aircraft movements using one runway. It could be explained as part of error or uncertainty due to the approximated definition of Japanese WECPNL, which was derived from the original ICAO definition under several assumptions, but it became a matter of political concern; local authorities around the airport filed a petition with the Ministry of the Environment so as to revise the Standard.

In response, the Ministry revised it to use $L_{den}$ instead of WECPNL at last in the end of last year. It is now in progress to prepare a new guidance material for evaluation of cumulative noise exposure levels in $L_{den}$ by measurement. Thus, taking this opportunity, we made an examination of the validity of the way to determine cumulative noise exposure levels specified in the Standard, e.g., how to determine single event and yearly-averaged cumulative noise exposure levels at various sites around all types of airports. The Standard requests determination of annual-averaged cumulative noise exposure levels, being based on repetitive short-term noise measurements. We have never examined the validity of such procedures thoroughly up to now.

2 REVISED ENVIRONMENTAL QUALITY STANDARD

The basic purpose of the amendment of the EQSAN this time was to resolve an unreasonable but subtle error resulting in the calculation of cumulative noise exposure levels, and the general idea and content of the EQSAN were maintained the same as before.

Several points which were changed in the revised Standard are as follows;

- Use of $L_{den}$ as noise index for evaluation of cumulative noise impact of all noise events a day, instead of WECPNL. The time frame of three time-periods is the same as before; daytime/07:00-19:00, evening/19:00-22:00 and nighttime/22:00-07:00.
- Expansion of target sounds of noise evaluation; it was decided to take account of contributions of sounds resulting from aircraft operations on the airport ground surface such as thrust reversal on the runway after landing, taxiing, engine run-up and use of auxiliary power units on the apron, etc., if necessary. Generally speaking, such sounds have ineffective contributions to the cumulative sound exposure except in the proximity of the airport.
- Expansion of target airports; all types of airports including heliports have become the target of application of the new EQSAN except small airfields which are exclusively used for police, fire fighting and defense forces or those which are located in isolated islands. Note, at the exceptions the total aircraft movements a day must be less than 10.
- Modified standard values of 57dB and 62dB in $L_{den}$ respectively for exclusively residential areas and for other areas where good living environment must be preserved.
- It was also decided to enforce the new EQSAN from April 1, 2013, by considering a period necessary to prepare for noise measurement using the new noise index of $L_{den}$.

On the other, several points kept the same as before are as follows;

- Perform a short-term (i.e., consecutive seven-day) outdoor noise measurement as the basis for a check whether an area satisfies noise requirements specified in the EQSAN.
- Select a measurement location which is representative for the situation of aircraft noise exposure in the relevant area.
- Select time periods which are identified as representative for the situation of aircraft noise exposure at the measurement location, by taking aircraft flyover situations and meteorological conditions such as wind direction into account.
- Take noise events that maximum sound levels are ten decibels or more higher than the residual sound into account.
3 VALIDITY OF YEARLY-AVERAGE $L_{den}$ BY SHORT-TERM NOISE MEASUREMENT

3.1 Needs for short-term noise measurement

As stated above, the EQSAN requires evaluation of yearly-average cumulative noise exposure level in $L_{den}$, which is basically estimated by short-term noise measurement over a period of consecutive seven days at a location that aircraft noise situation is typical of the area. If the situation changes strongly from a season to another, short-term noise measurement must be repeatedly performed twice a year, in summer and winter, or otherwise four times a year in each season. Short-term noise measurement is also performed as a means supplementary to unattended continuous aircraft noise monitoring, because of limited numbers of sound monitors, when examining the validity of noise zones established for environmental countermeasures around major civil airports and defense force airfields.

It has been, however, a matter of concern whether we can really make a valid determination of long-term average cumulative noise exposure level by short-term noise measurement. In other words, what is the reliability of $L_{den}$ estimations obtained from short-term noise measurement? Noise exposure situation changes every moment and from place to place, dependent on various causes such as changes in runway use due to wind conditions, scatters of flight tracks and altitudes due to air traffic control, changes of sound propagation due to meteorological conditions and so on. Needless to say, all these cause strong fluctuations in daily cumulative noise exposure situation throughout the year. It may not be possible to be averaged out by taking an energy-average of daily cumulative noise exposure levels $L_{den}$ over a short-term period.

3.2 Variability in short-term average $L_{den}$ estimations dependent on the measurement period

Thus, we examined fluctuations of short-term average of consecutive observations of daily cumulative noise exposure levels in $L_{den}$, using one-year long records of noise observations by unattended noise monitoring at various points around several civil airports and defense force airfields [3]. The period of consecutive observations for averaging (i.e., averaging period) was changed from “one day”, “one week”, “two weeks” and “30 days (~four weeks)”. “One day” means the original daily data itself. “One week” is a reference period (consecutive 7 days) used in the EQSAN, whereas “two weeks” is a reference period (consecutive 14 days) used for noise measurement around defense force airfields.

Figure 1 shows two illustrations depicting changes of short-term average $L_{den}$; upper figure is a result for noise observations at a point between two flight paths around a major international airport and lower figure is a result for noise observations at a point below the flight path around a defense force airfield. Note that a yearly-average $L_{den}$ is also depicted as a horizontal straight line in the figure. What you can see from these line graphs are as follows;

- The longer the averaging period becomes, the smaller the fluctuation of $L_{den}$ becomes, but a certain fluctuation remains even if the period is set to thirty days.
- The result of a civil airport in the upper figure suggests that a seasonal fluctuation of a few decibels around the yearly-average may remain even if the total of aircraft movements a day is almost the same through the year.
- On the other hand, the result of a defense airfield in the lower figure suggests that a great fluctuation of several decibels or more may remain because of an irregular large change in the total of aircraft movements from day to day.
Figure 1: Change of short-term average $L_{den}$ dependent on the averaging period; (Upper) at a point on the side between two flight paths around a civil airport (Lower) at a point below flight path around a defense force airfield.
Figure 2 shows line graphs of standard deviation (STD) values of level fluctuation in short-term average $L_{\text{den}}$ estimations around the yearly average, dependent on the averaging period:

1. “One day,”
2. “Consecutive one week,”
3. “Consecutive two weeks,”
4. “Consecutive four weeks.”

These graphs also show STD values of level fluctuation in short-term average $L_{\text{den}}$ estimations obtained from seasonally repeated short-term measurements:

5. “Two weeks (i.e., one week every six months, or twice a year in summer and winter),”
6. “Four weeks (i.e., one week every three months, or four times a year in each season).”

The upper figure is the result for civil airports, whereas the lower figure a result of defense airfields. What you can see from these graphs are as follows;

- The longer the averaging period becomes, the smaller the STD of a consecutive short-term measurement is. The trend is the same between civil and defense, but roughly speaking, the STD is two times greater for defense than for civil.

- On condition that the total of measurement days is the same, STD of seasonally repeated short-term measurements becomes small, compared with that of a consecutive short-term measurement; for example, in case of two-week measurement around civil airports, STD of a twice-a-year measurement (every six months) is 0.66 dB, while STD of a consecutive two-week measurement is 1.15 dB.

- In case of civil airports, STD becomes lower than 1 dB or if we perform seasonally repeated short-term measurements (twice a year or four times a year). It suggests the validity of the method of $L_{\text{den}}$ estimation specified in the EQSAN.

- In case of defense airfields, STD remains higher than 2~3 dB even if we perform a seasonally repeated short-term measurements or a consecutive four-week measurement. It suggests the validity of a method of estimating cumulative noise exposure levels around defense facilities, in which we are requested to evaluate effective level of cumulative noise exposure using upper bound of 80 % percentile range of the frequency distribution of daily aircraft operations (take-off and landing) throughout the year.
Figure 2: Standard deviation of fluctuation in short-term average $L_{den}$ estimations around the yearly average; (Upper) at a point between two flight paths around a major civil airport (Lower) at a point below flight path around a defense force airfield.
4 IMPROVEMENT OF THE RELIABILITY OF YEARLY-AVERAGE $L_{den}$ ESTIMATION

As shown above, short-term noise measurement repeated twice (one-week in summer and in winter) or four times (one-week for each season) a year makes it possible to get a precise estimation of yearly-average $L_{den}$. It is, however, STD around the yearly-average remains to be 0.6~1.0 dB at the lowest, which is not always sufficient for a precise examination of the validity of noise zones, etc. Thus, in such cases, it is necessary to improve the reliability of the method of yearly-average $L_{den}$ estimation; one way is to use result of unattended continuous noise monitoring over a long period including the period of short-term measurement at a near-by location. Another is to calculate yearly-average $L_{den}$ using both single event sound exposure levels and yearly-average statistics of aircraft movements for each flight mode (take-off and landing) and for each runway. Here, we made a check of the effectiveness of the former method

4.1 Equation to improve the reliability of yearly-average $L_{den}$ estimation

Generally speaking, if an unattended noise monitor is installed close to a point of short-term noise measurement and if aircraft flyover situations at these points are similar to each other, it is expected that noise exposure situation at these points are similar to each other, too. Thus, if there is an unattended noise monitor at a reference point $P_r$ near a point $P_s$ of short-term noise measurement and if noise exposure situations at these points are highly correlated each other, it is possible to estimate yearly-average cumulative noise exposure level $L_{den,year,P_s}$ at $P_s$ by adding the difference of yearly-average $L_{den,year,P_r}$ and short-term average $L_{den,short,P_r}$ at $P_r$ to short-term average $L_{den,short,P_s}$ at $P_s$ as follows;

$$L_{den,year,P_s} = L_{den,short,P_s} + (L_{den,year,P_r} - L_{den,short,P_r})$$  \hspace{1cm} (1)

4.2 Examination of the validity of the method of improving the reliability

We made an examination of the effectiveness of Equation (1) using one-year long noise observations at many unattended aircraft noise monitors installed around a major international airport as follows;

i) Select two noise monitors where noise exposure situations are similar to each other,
ii) Select one as a point of short-term measurement, and consider another as a reference,
iii) Calculate yearly-average $L_{den,year,P_r}$ and $L_{den,year,P_s}$,
iv) Select a period of short-term noise measurement,
v) Calculate yearly-average $L_{den,year,P_s}$, using Eq.(1),
vi) Repeat steps iv) and v) until the end of noise observations,
vii) Compare result with actual yearly-average $L_{den,year,P_s}$ to calculate STD. Examination was repeated for the following six periods the same as before; (1) one day, (2) consecutive one week, (3) consecutive two weeks and (4) consecutive four weeks, (5) two weeks (one week every six months) and (6) four weeks (one week every three months).

Figure 3 shows the result of the examination; STD vs. period of short-term noise measurement. Tables below the graphs show a comparison of STD values for each period among actual measurement, estimation and the difference between measurement and estimation as improvement. These tables suggest that Eq. (1) makes it possible to improve the reliability of yearly-average estimation sufficiently as far as we can select an appropriate reference point; in case of civil airports, STD becomes equal to or lowers than about 0.3 dB if we perform seasonally repeated short-term measurements. On the other hand, in case of defense airfields with a very unstable aircraft flyover situation, STD remains around 1.5 dB even if we perform short-term noise measurements four times a month.
a major international airport: comparison of average STD among monitors in dB

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a defense force airfield: comparison of average STD among monitors in dB

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Figure 3: STD of yearly-average estimations at a major international airport and a defense force airfield.
5 RELIABILITY OF PRACTICAL METHODS OF $L_{AE}$ AND $L_{ASmax}$ ESTIMATION

5.1 $L_{AE}$ estimation

First, we checked the magnitude of error in $L_{AE}$ estimation by true integration due to a limited time interval of integration. We calculated $L_{AE}$ values over various time intervals; $L_{AE,x}$dB means an estimation of $L_{AE}$ which was obtained by true integration of the squared A weighted sound pressure $L_{PA}$ over a time interval where $L_{PA}$ stays above a threshold of $L_{ASmax}$-x” (x=5~30). As a result, based on a definition of $\Delta L_{diff,x}$dB as level difference of $L_{AE,x}$dB and $L_{AE,30}$dB, we obtained that in case of a straight flight path $\Delta L_{diff,20}$<$-0.1$dB, $\Delta L_{diff,15}$dB~$-0.1$dB and $\Delta L_{diff,10}$dB~$-0.5$dB, whereas in case of a circular flight path $\Delta L_{diff,15}$dB~$-0.5$dB and $\Delta L_{diff,10}$dB becomes $-1.0$dB.

Next, we examined the validity of a practical method of $L_{AE}$ estimation by the square-sum of discrete samples of AS-weighted sound pressure $P_{AS,T}$ obtained at a rate $T_s$. The result was consistent with that obtained by true integration within a difference less than 0.1dB, provided that the sampling rate was set to 100ms or less and background noise was sufficiently low.

Thirdly, we examined the validity of the following four practical $L_{AE}$ estimation methods, using records of either AS-weighted sound pressure levels $L_{pAS,100ms}$ or one-second A-weighted time average sound pressure level $L_{Aeq,1s}$ over a period of aircraft flyover;

- $L_{AE,100ms,x}$dB: an estimate by summing up the squared sound pressure over a time interval where sound pressure stays within x dB below $L_{ASmax}$ (x=15 and 10). $L_{ASmax}$ was determined as the maximum of $L_{pAS,100ms}$ over the time interval.
- $L_{AE,eq,1s,10}$dB: an estimate by summing up $L_{Aeq,1s}$ as sound energy over a time interval where $L_{Aeq,1s}$ stays within 10dB below $L_{Aeq,1s,max}$.
- $L_{AE,Dur}$, $L_{ASmax}$ with an adjustment for 10dB-down duration, where $L_{ASmax}$ and duration are obtained using the records of either $L_{pAS,100ms}$ or $L_{Aeq,1s}$.

Note that data used were obtained around a major international airport, a major domestic airport and a defense force airfield, where a lot of large jet aircraft and fighters usually flew and we could observe aircraft noise events under various background noise situations. The level of $L_{ASmax}$ scattered in a wide range of 70~110dB, but it was not possible to determine $L_{AE,100ms,15}$dB because of poor S/N ratio conditions.

As a result, the following are found; 1) $L_{AE,100ms,10}$dB was the most stable and reliably means of $L_{AE}$ estimation, although $L_{AE,100ms,15}$dB was superior in precision. 2) Result of $L_{AE,eq,1s,10}$dB was almost similar to $L_{AE,100ms,10}$dB and it was considered to be a stable means in most cases. It sometimes, however, causes a significant underestimation because of mainly poor S/N ratio conditions. 3) Scatter of $L_{AE,Dur}$ was rather strong compared with others. Roughly speaking, it was within 2dB around $L_{AE,15}$dB.

We also examined the validity of the way to determine $L_{Aeq,1s}$ using records of either AS-weighted sound pressure levels $L_{pAS,100ms}$. The examination was performed using data observed at two points around a major international airport. We calculated $L_{Aeq,1s}$ by taking an energy sum of ten consecutive samples of $L_{pAS,100ms}$ and compared the results with those obtained as defined using an integrating sound level meters. The result was satisfactory; the difference between the two, $L_{Aeq,1s}$ and $L_{pAS,100ms}$, in average and STD was $-0.16$dB and 0.94dB at point 1, and $-0.01$dB and 0.4dB at point 2.

5.2 $L_{ASmax}$ estimation

We also tried to examine the validity of the following three practical methods of $L_{ASmax}$ estimation; 1) $L_{ASmax,peak-held}$: an estimate by performing peak-hold operation using a sound level meter, 2) $L_{ASmax,100ms}$: an estimate by detecting the maximum of $L_{pAS,100ms}$ and 3)
LASmax,eq,1s: an estimate by detecting the maximum of L_{Aeq,1s}. Note data was limited to several tens samples at two points around a major international airport. As a result, the difference between LASmax,100ms and LASmax,peak-held was small and negligible (average; -0.06dB, STD; 0.1dB). On the other hand, the difference between LASmax,eq,1s and LASmax,100ms was rather strong and scattered from +1.1~2.1dB (average; +0.5dB, STD; 0.5dB). In other words, LASmax,eq,1s was usually a bit higher than LASmax,100ms, but the situation was sometimes reversed.

6 CONCLUSIONS

This paper discussed the validity of methods of estimating long-term average cumulative aircraft noise exposure, measured in L_{den}, around the airport in relation to the revision of the Environmental Quality Standard for Aircraft Noise in Japan. First, it gave a brief summary of the revision, in which noise index for evaluating aircraft noise was changed from WECPNL to L_{den}. Secondly, it discussed the reliability of evaluation of yearly average L_{den} by short-term noise measurement. It was confirmed that in case of civil airports power average of one-week measurements repeated seasonally twice or four times a year makes it possible to get a good estimation of annual average cumulative noise exposure. Finally, it discussed practical methods of estimating L_{AE} and LASmax under various background noise situations around airports.

7 ACKNOWLEDGEMENTS

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8 REFERENCES

