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Conversion Relationship of Aircraft Noise Indices between WECPNL and DENL

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ABSTRACT

The movement to improve the aircraft noise index from WECPNL to DENL has been arisen in the recent days in Korea. It is indispensable to determine a conversion formula of the aircraft noise index in order to bring up the outlines of the current aircraft noise regulations and guidelines for modification as a function of the revised noise index. It is essential to make full use of the past aircraft noise measurements data and aircraft noise maps in WECPNL during about 20 years in order to save the additional expense. Japan suggested that the relationship between WECPNL and DENL via unattended noise monitoring around various airports. But the airport environments and the noise level range distributions in Korea are different from those in Japan because the percentages of joint-use airport are different each other. Therefore, the current paper derives a conversion formula between WECPNL and DENL which can be adaptable to the airport environments. In doing so, the noise levels of commercial and joint-use airports are calculated in WECPNL and DENL, and compared each other using the unattended noise monitoring data around various airports to investigate and clarify the relationship between WECPNL and DENL. The unattended noise monitoring data around Gimpo international airport was analyzed to investigate and to clarify the conversion formula 'DENL= 0.7683WECPNL+2.2993' between WECPNL and DENL.

INTRODUCTION

Aircraft noise reduction is one of the challenges that both the national government and air-transportation industry have to face because of the resident demand as well as increasing the international legal restrictions. The accurate assessment and measurement of aircraft noise are playing major roles in the developing of new noise policy and noise zoning. The aircraft noise indices can be divided into noise emission index and noise immission index. Most countries, including South Korea, are required to follow the ICAO (International Civil Aviation Organization) regulations for aircraft noise emissions, but most also have noise immission regulations concerning aircraft noise intrusion into the community in the airport surrounding area. For aircraft noise immission indices, the most common noise index is LEQ(24) or some variant of this, such as the Day-Night Average Sound Level (DNL or L_{dn}), or Day-Evening-Night Average Sound Level (DENL or L_{den}). The use of WECPNL is declining around the world, although some countries such as Korea, China and Japan have still been using $WECPNL_J$ (Japanese WECPNL) based on L_{max}, which is a variant of ICAO WECPNL. In December 2007, Japan Government decided to change from $WECPNL_J$ to L_{den} as the noise index for evaluation of cumulative noise exposure levels in the vicinity of airports.

In 1991, Korea Government designated WECPNL as the aircraft noise index to assess aircraft noise disturbance near major airports in the Aviation Act. But in the recent days, the movement to change the aircraft noise index from WECPNL to DENL has been arisen because WECPNL has a lower general-purpose availability compared to LEQ series and has shortcomings for comprehension to the public and application with other types of transportation noise sources such as vehicles and trains. The research on the improvement of aircraft noise assessment method and establishment of environmental quality standard was performed by Seoul National University which is supported by The Ministry of Environment and Airport Corporation from June 2008 to January 2009.

It is indispensable to determine a conversion formula of the aircraft noise index in order to bring up the outlines of the current aircraft noise regulations and guidelines for modification as a function of the revised noise index. Moreover, a conversion formula is also essential to make full use of the past aircraft noise measurements data and aircraft noise maps in WECPNL during about 20 years in order to save the additional expense. I. Yamada suggested that the relationship between WECPNL and DENL is 'DENL−WECPNL≈−13dB' via unattended noise monitoring around various airports in Japan. But this formula holds only when WECPNL becomes within the ranges of 70-80 dB, so it would not be applicable correctly to the areas beyond those noise level ranges. Moreover, the airport environments are different from those in Japan because the percentage of joint-use airport respect to all the commercial airports in Korea and in Japan is 53.3% and 15.5%, respectively.

The current paper, therefore, aims to derive a conversion formula between WECPNL and DENL which can be adaptable to the airport environments. In doing so, the noise levels of commercial and joint-use airports are calculated in WECPNL and DENL, and compared each other. The unattended noise monitoring data around international and domestic airports were analyzed to investigate and clarify a conversion relationship.

QUANTIFICATION OF AIRCRAFT NOISE

Principle of Energy Equivalence

The principle of energy equivalence is that human responses are the same if they are exposed to a loud noise occasionally and a quieter noise more often and if those acoustic energy levels are the same. This method is considered to have accuracy and completeness which is suitable in developing a noise contour map for noise management around the airports. Most conturies adopted this method and typical indices are DNL/DENL, ANEF/NEF (Noise Exposure Level), NNI (Noise and Number Index), ICAO WECPNL (Weighted Equivalent Continous Perceived Noise Level).

Maximum Sound Pressure Level

This quantification method is refered to a maximum sound pressure level of a noise event which is accord with the number of occurrences of a noise event. And the measurement and calculation procedures have simplicity. The representative noise indices are NA (Number Above Index), Korean WECPNL (hereafter $WECPNL_K$).

Aircraft Noise Quantification Level in Korea

the Aviation Act by the Ministry of Land, Transport and Maritime Affairs and the Noise and Vibration Control Act by the Ministry of Environment specify outdoor aircraft noise standards and areas, as shown in Table 1, using $WECPNL_K$.

$$WECPNL_K = \overline{L_A} + 10\log(N_2 + 3N_3 + 10(N_1 + N_4)) - 27 \quad (1)$$

where $\overline{L_A}$ denote the energy average of maximum A-weighted sound pressure levels, greater than the background noise by 10 dB or more, of aircraft noise events observed during a day. N_1 is the number of events observed during night time (00:00–07:00) and N_2 is the number of events observed during day time (07:00–19:00). N_3 and N_4 are the number of events during evening time (19:00–22:00) and night time (22:00–24:00), respectively.

Table 1. Aircraft Noise Influence Regions

Division	*Types of areas*	*$WECPNL_K$*	
Aircraft noise influence region	I	More than 95	
	II	90 up to 95	
Estimated aircraft noise influence region	III	Zone A	85 up to 90
		Zone B	80 up to 85
		Zone C	75 up to 80

DENL and DNL were also used for evalutation of cumulative noise impact of all noise events a day, instead of $WECPNL_K$.

DENL has been calcultated based on the formula:

$$DENL = 10\log\left[\frac{12}{24}10^{0.1L_d} + \frac{3}{24}10^{0.1(L_e+5)} + \frac{9}{24}10^{0.1(L_n+10)}\right] \quad (2)$$

where L_d, L_e and L_n represent the day, evening and night-time average sound levels, respectively. The day-time period runs from 07:00 to 19:00. The evening-time period and the night-time period run from 19:00 to 22:00 and 22:00 to 07:00, respectively. The time frame of three time-periods is the same as $WECPNL_K$.

DNL is determined by

$$DNL = 10\log\left[\frac{15}{24}10^{0.1L_d} + \frac{9}{24}10^{0.1(L_n+10)}\right] \quad (3)$$

where L_d and L_e are the day and night-time average sound levels, respectively. The time frame of day-time period is 07:00-22:00 and night-time period 22:00-07:00.

ANALYSIS METHODOLOGY

To assess conversion relation between L_{Aeq}-based metric and $WECPNL_K$, we conducted a field noise measurement program at select sites throughout the international and domestic airports to provide a sample of ambient, aircraft events and cumulative noise values for consideration. The primary focus of the measurement analysis program was to collect and calculate the $WECPNL_K$, DNL, DENL at each specific site. The noise measurements contain all noise recored at a site, and have been parsed into the noise contributions from both aircraft and non-aircraft sources.

Site Selection / Noise Measurement

The noise measurement analysis program was conducted in two methods. The first method was performed between April 4 and April 12, July 6 and 12, September 7 to 13, 2008. Measurements were conducted at 12 sites throughout the research area around Gimpo international airport, for a continuous 7 day period for each site. The raw noise measurements data with aircraft landing and take-off informantion were supported by the Ministry of Land, Transport and Maritime Affairs. Total 6,804 aircraft noise events were analyzed. The second method of measurements was conducted between January 2004 and June 2006. Measurement was conducted at six or seven sites for a 7 day period. The number of measurement site is different from each airport, as shown in Table 2. The raw noise measurements data were supported by the Ministry of Environment.

Noise Level Indices

In addition to the total LEQ and maximum sound level at each monitoring site, several other metrics were computed from the measured data to analyse aircraft noise levels which describe community response adequately. These include the following:

- Aircraft Event DENL (or DNL) – The DENL (or DNL) value of only the noise events that were correlated with aircraft overflights based on the radar flight track data.
- Total DENL (or DNL) – The DENL (or DNL) value of noise resulting from the Total LEQ measured at each site.

- Aircraft Event L_{Amax} – The A-weighted maximum sound level associated with the correleated aircraft events.
- Most common types of aircraft noise events (take-off, landing, overflight)

Table 2. Aircraft Noise Monitoring Airports

Airport	*Main role*	*Sites*	*Measurment*
Gimpo international	Civil	12	Jan.2007-Sep.2008
Jeju international	Civil	7	Jan.2004-Jun.2008
Daegu domestic	Joint use	7	Jan.2004-Jun.2008
Gwangju domestic	Joint use	7	Jan.2004-Jun.2008
Gunsan domestic	Joint use	6	Apr.2005-Jun.2008
Yangyang domestic	Civil	6	Jan.2005-Jun.2008
Yeosu domestic	Civil	6	Jan.2004-Jun.2008
Wonju domestic	Joint use	6	Apr.2007-Jun.2008

RESULTS AND DISCUSSIONS

Calculation of L_{max} based $WECPNL_K$

In 1971, WECPNL was recommended by ICAO to measure and to evaluate the aircraft noise. This noise evaluation method is based on the EPNL which used for aircraft noise certification test and measurement conditions. $WECPNL_K$ is modified from ICAO WECPNL to simplify the measurement and evaluation of the aircraft noise as follows:

$$WECPNL_{ICAO}=10\log\left[\frac{d}{24}10^{0.1ECPNL_d}+\frac{e}{24}10^{0.1(ECPNL_e+5)}+\frac{n}{24}10^{0.1(ECPNL_n+10)}\right]+S \quad (4)$$

$$EPNL=10\log\left[\sum_{k=0}^{dur/\Delta t}10^{0.1PNLT}\right]-13 \quad (5)$$

$$EPNL\approx SEL+3\cong L_{AS\max}+10\log\left(\frac{T_{dur}}{20}\right)+13 \quad (6a)$$

$$ECPNL=10\log\left(\frac{1}{N}\right)\left[\sum_{i=1}^{N}0.1EPNL_i\right]+10\log N-39.4 \quad (6b)$$

$$ECPNL\approx 10\log\left(\frac{1}{N}\right)\left[\sum_{i=1}^{N}10^{0.1L_{ASmaxi}}\right]+10\log\left(\frac{T_{dur}}{20}\right)+13+10\log N-39.4 \quad (6c)$$

$$WECPNL\approx \overline{L_{ASmax}}+10\log\left[\gamma_d N_d+\gamma_e N_e 10^{0.1\times 5}+\gamma_n N_n 10^{0.1\times 10}\right]-26.4 \quad (7a)$$

$$WECPNL\approx \overline{L_{ASmax}}+10\log[N_d+3.162N_e+10N_n]-26.4 \quad (7b)$$

$$WECPNL_K\equiv \overline{L_{AS\max}}+10\log[N_d+3N_e+10N_n]-27 \quad (7c)$$

where $ECPNL_d$, $ECPNL_e$, $ECPNL_n$ are the day-time period, the evening-time period and the night-time period equivalent continuous perceived noise level, respectively. Symbol d, e and n mean the each time period (d=12, e=3, n=9). S is the correction factor for seasonal effects. PNLT is the tone corrected perceived noise level. The value of PNL adjusted for the spectral irregularities that occur at any instant of time. γ_d, γ_e and γ_n are the rates of aircraft noise events per hour for each time period. N_d, N_e and N_n are the numbers of aircraft noise events for the time-period.

In equation (4), WECPNL recommended by ICAO contains the seasonal effect for considering the air absorption of sound and the weighted factors 5 dB and 10 dB for evening-time and night-time, respectively. Equation (5) is the definition of EPNL (Effective Perceived Noise Level) in ICAO Annex 16. The procedure to obtain WECPNL from EPNL is complicated and needs substantial computation costs. $WECPNL_K$ is simplified from ICAO WECPNL and modified as the noise index based on the maximum sound pressure level througth the four assumptions. The first assumption form a relation between PNLTM (Maximum Tone Corrected Perceived Noise Level) and L_{max} (Maximum Sound Pressure Level), that is:

$$PNLTM=L_{max}+13 \quad (8)$$

This equation could be applied only for the particular cases. According to the former research using INM (Integrated Noise Model) by FAA, the difference between EPNL and L_{max} is decreasing as the distance between the aircraft and the observer position is getting closer. But the difference is increasing as the distance is increasing. So, this assumption is not adaptable to general measurement cases and the correction factor must be varied according to the distance between the aircraft and the observer position. The simplifted EPNL (6a) is coupled with the definition of ECPNL (6b) and ECPNL resulted in the approximated from of ECPNL (6c).

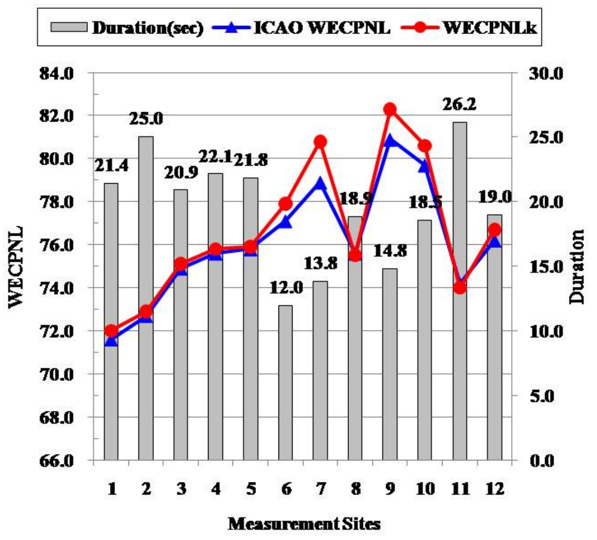

Figure 1. Relationship of ICAO WECPNL with $WEPCNL_K$

The second assumption is that the duration of the aircraft noise event is always constant as 20 seconds and the seasonal correction factor can be omitted. This simplification employed for omission of an event duration term $10\log\left(\frac{T_{dur}}{20}\right)$.

It is considerable to adapt this 20 seconds assumption for civil aircrafts because noise event durations are generally 20 seconds. But the durations are shorter than 20 seconds as the noise observation locations are varied. Otherwise, the noise event durations are longer than 20 seconds because of the directivity of noise propagation to the grounds by high take-off aircraft engine thursts and increased take-off angles. These effects form the increased errors of noise anlaysis.

Sites from 6 to 10 are mainly located at the direction of aircraft landing. Except for the site 8 which is far away from the axis of aircraft landing, the noise event durations at sites 6, 7, 9 and 10 are below 20 seconds because of the low thrust landing procedure. In particular, the site 7 and 9, located on the extension line of the runway, showed the highest noise levels and their noise event durations are 13.8 seconds and 14.8 seconds, respectively. These cases are not matched with the 20 seconds duration assumption. $WECPNL_K$ level of site 7 is 1.9 dB higher than ICAO WECPNL level. For site 9, $WECPNL_K$ level is 1.4 dB higher than ICAO WECPNL level (Figure 1).

The third assumption is that the average value of 1-day maximum noise level is the same as the average value of day-time maximum noise level, that of evening-time maximum noise level and that of night-time maximum noise level. Equation (7a) is simplified to equation (7b) by this assumption. This is appropriate only for civil aircrafts, because this implies that the measured maximum noise level at a specific oberserver location is not varied with the types, running times and take off/landing patterns of aircrafts. But this constant average maximum noise level assumption could not be applicable to military aircrafts because the calculation errors are increased by the various types and take off/landing paterns.

The last assumption showed that the constant values of equation (7b) were simplified to those of equation (7c). In $WECPNL_K$ the weighted factors for the time frame of three time-periods (1 for the number of day-time period noise events, 3 for evening-time and 10 for night-time). These are originated from the weighted factors 5 dB and 10 dB for the evening-time period noise level and the night-time period noise level, respectively.

Validity of Aircraft Event DENL based on Repetitive Short-term Noise Measurements

In the present study, numerical analysis of airports is performed with our aircraft noise calculation model. The objective of this validation is to reduce the calculation errors originated from aircraft noise events measurements beyond the four former assumptions in $WECPNL_K$. The adaptability for use of Aircraft Event DENL as noise index for evaluation of cumulative noise impact of all noise events a day, instead of $WECPNL_K$ were analysed. The characteristic of aircraft noise is intermittent unlike road traffic noise and residential noise. The term 'Event' means that only aircraft noise event is used for the calculation of cumulative noise exposure level, DENL unlike 'Total' LEQ which includes background noise effects. Aircraft Event DENL is defined as

$$L_{AE(i)} = \sum_{t=1}^{T_{dur}} L_{AE(t)} \tag{8}$$

$$DENL = 10\log\left[\sum_{i=1}^{N_d} 10^{0.1L_{AE(i)}} + \sum_{j=1}^{N_e} 10^{0.1L_{AE(j)}} + \sum_{k=1}^{N_n} 10^{0.1L_{AE(k)}}\right] - 49.4 \tag{9}$$

where $L_{AE(i)}$ is a calculated SEL (Sound Exposure Level) when the i-th aircraft was overflighted. T_{dur} and $L_{AE(i)}$ are a noise event duration and 1-second duration measured SEL, respectively. Equation (8) is 1-day DENL and the weighted factors 5 dB and 10 dB are applied to evening-time SEL and night-time SEL, respectively. N_d, N_e and N_n are the number of day-time noise events, the number of evening-time events and the number of night-time noise events, respectively. The constant -49.4 is $10\log\left(\frac{1}{86400}\right)$ and is generated from 1-day average calculation.

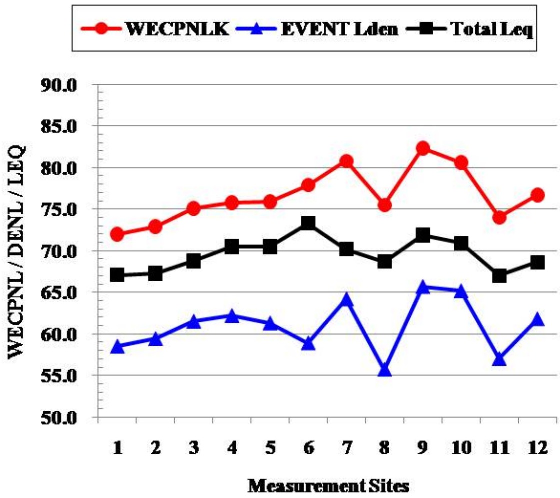

Figure 2. Comparison of average noise levels in $WEPCNL_K$, Aircraft Event DENL and Total LEQ (Gimpo)

Total LEQ which includes background noise effects showed no considerable difference between low noise level zones (site 4, 5) and high noise zones (site 7, 10). But Aircraft Event DENL which considered only aircraft noise event showed exact noise level difference between those two zones (Figure 2).

Analysis of Conversion Correlation between $WECPNL_K$ and DENL

To change noise index from a maximum sound pressure level metric to an energy-based metric, the relationship between two metrics must be defined. As a result of applicability of DENL instead of $WECPNL_K$, the conversion correlation between $WECPNL_K$ and DENL were analysed. Recently, Japan revised the Enviromental Quality Standards to replace noise index from WECPNL to a L_{Aeq}-based metric. I. Yamada showed the relationship between WECPNL(J) and DENL obtained via unattended noise monitoring around various airports in Japan as follows:

$$DENL = WECPNL_J - 13 \tag{10}$$

Equation (10) only holds when WECPNL(J) becomes 70-80 dB ranges. The correlation error is increased by this restriction below 70 WECPNLdB noise zone or above 80 WECPNLdB zone. The calculation formula of WECPNL(J) and $WECPNL_K$ are very similar. But equation (10) could not be applied to airport noise assessment because the aircraft noise sources and types of airports are different from each other. The percentage of civil-military joint use airport in Japan is 15.5 % but in Korea, the percentage of joint use airport is 53.3 %. So the average noise levels near airports are higher up to 110 WECPNL dB.

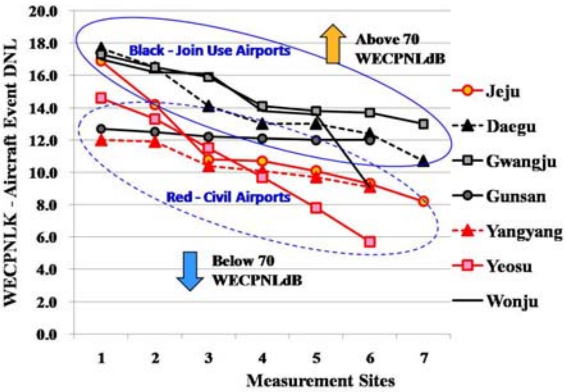

Figure 3. Correlations of $WECPNL_K$ and Aircraft Event DNL (except Gimpo)

To define the appropriate correation equation, another noise index of aircraft noise events DNL was analysed. DNL (or L_{dn}) is widely used as aircraft noise index in United States and some EU conturies. The time frame of two time-periods is the same as follows: day-time/07:00-22:00, night-time/22:00-07:00. The definition of Aircraft Event DNL is given by

$$DNL = 10\log\left[\sum_{i=1}^{N_d} 10^{0.1L_{AE(i)}} + \sum_{j=1}^{N_n} 10^{0.1L_{AE(j)}}\right] - 49.4 \qquad (10)$$

Figure 3 shows the difference between $WECPNL_K$ and Aircraft Event DNL. Civil airports are in red color and their average noise levels are lower than 70 WECPNLdB, otherwise joint use airports are in black color and their average noise levels are higher than 70 WECPNLdB.

Figure 3 also shows that the relationship between $WECPNL_K$ and Aircraft Event DNL The difference between two metrics above 70 WEPCNLdB noise zones which mainly includes joint use airport is in 11-18 ranges and its average value is 13.8. On the otherhand, the difference below 70 WECPNLdB noise zones which are composed of civil airports is in the range of 6 to 17 and average value is 10.8. Thus, the relationship between $WECPNL_K$ and Aircraft Event DENL could not be defined as a constant conversion formula but must be defined as appropriate one.

We combined Gimpo measured aircraft noise data with I. Yamada's data because there are no measured results below 70 WECPNLdB near Gimpo international airport. Figure 5 shows that the conversion error is increased when $WECPNL_K$ is over 70 dB. Using the trend line, the induced exact conversion equation and the simplified formula are derived as follows:

$$DENL = 0.7683WECPNL_K + 2.2993 \qquad (11)$$

$$DENL = 0.8WECPNL_K \qquad (12)$$

Equation (11) becomes a exact conversion equation and equation (12) which is a simplified and convenient form could be used for environmental noise politics. This conversion equation has two advantages compared with $WECPNL_K$ noise metric system. One is that a conversion error is less than 1 dB. And the other is that there is no restriction for WECPNL ranges (Table 4).

Table 4. Conversion Error Comparsion

	Noise Level [dB]				
$WECPNL_K$	50	60	70	80	100
Aircraft Event DENL	40.7	48.4	56.1	63.8	79.1
DENL=0.8$WECPNL_K$ (Conversion Error)	40 (-0.7)	48 (-0.4)	56 (-0.1)	64 (0.2)	80 (0.9)
DENL=$WECPNL_K$-13 (Conversion Error)	36 (-3.7)	46 (-1.4)	57 (0.9)	66 (3.2)	86 (7.9)

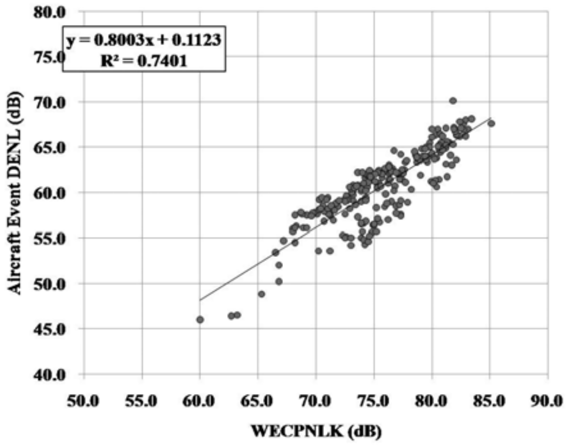

Figure 4. Relationship of $WECPNL_K$ with Aircraft Event DNL (Gimpo international airport)

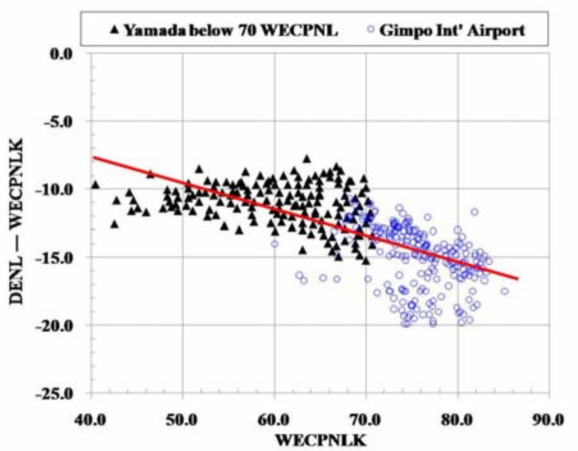

Figure 5. Relationship of $WECPNL_K$ with DENL-WECPNL

CONCLUSIONS

In this article the induction procedure of $WECPNL_K$ which is used as aircraft noise assessment index in Korea was analyzed and the validity of methods of energy based index, Aircraft Event DENL has been studied to solve the problems which are generated from the simplification assumptions. The unattended aircraft noise measurement data were analysed by the developed aircraft noise prediction and analysis program for each seven days of April, July and September 2008. The first assumption 'PNLTM=L_{max}+13' and the second assumption that the noise event duration is constant as 20 seconds make to predict the take-off noise more higher than the exact noise level. The assumption that the maximum noise level in a day is independent of the aircraft types and air operation pattern is not appropriate to airport environments in Korea. On the other hand, the average cumulative aircraft noise exposure, measured in Aircraft Event DENL has advantage of exclusion of background noise compared to LEQ, consideraton of exact event duration, acquaintance because of using dB(A) metric. The developed conversion equation 'DENL = 0.7683WECPNL+2.2993' from $WECPNL_K$ to Aircraft Event DENL has no restricted range for application and has minimun conversion errors compared to the existing conversion formula. It is possible to get a good estimation for the existing aircraft noise data in $WECPNL_K$.

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