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TECHNICAL REPORT

Effect of measurement-based noise source model of military airplanes on the validity of aircraft noise estimation in Vietnam

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Abstract: Noise map provides a basis for land-use and flight path planning to limit the noise impact on residents around airports. This study is one of the first attempts to access an appropriate method to create noise maps for airports in Vietnam. In this study, the L_{den} around Noi Bai International Airport (NBIA) was predicted by using the Integrated Noise Model (INM) with available Noise-Power-Distance (NPD) data in INM and NPD data of military airplane created based on the field measurement. Besides, to assess the validity of the prediction, the predicted L_{den} was compared with the measured L_{den}, which were defined by field measurements conducted at ten residential sites around NBIA in November 2017. The noise levels were estimated with 3 cases: (1) Civil aircraft only, using INM's NPD; (2) Civil aircraft & military aircraft, using INM's NPD for military aircraft; (3) Civil aircraft & military aircraft, using measurement-based NPD for military aircraft. By comparing the root mean square error between the predicted and the measured values, it could be found that the prediction in Case 3 is the most consistent with the measured L_{den}. In other words, the prediction validity was improved by using measurement-based NPD of military aircraft.

Keywords: Aircraft noise, Military airplanes, Noise-power-distance, Vietnam, Noise estimation

1. INTRODUCTION

To better managing the noise environment around the airports while enhancing aviation traffic, the Vietnam government plans to produce noise maps for all 21 airports until 2020, based on the guideline of the International Civil Aviation Organization (ICAO) [1]. The noise map provides a basis for appropriate land-use and flight path planning to limit the noise impact on residents living in the vicinities of the airports. Many airports, including major airports located near residential areas in Vietnam, are used for both military and civil aircraft. Therefore, it is necessary to develop a prediction tool to produce an accurate noise map for the management of current and future noise environment around airports, especially for civil-military mixed-used airports.

An estimation based on actual flight operation conditions is essential to predict aircraft noise exposure around a specific airport precisely. However, some information needed to make a noise map is not available due to technical and security issues. In particular, there is no data on the sound source of military aircraft.

This study presents the first efforts of creating noise maps for the civil-military mixed-used airport in Vietnam using the Integrated Noise Model (INM) [2]. The targeted airport that is the second largest airport in Vietnam: Noi Bai International Airport (NBIA) shares the runways with the Vietnamese People's Air Force, so the noise maps must take into account the contributions of civil and military aircraft events. To produce the accurate noise map in the vicinities of the airport, the purposes of this study are creating measurement-based Noise-Power-Distance (NPD) data for a military aircraft and improving the accuracy of noise prediction by using the INM and the NPD.

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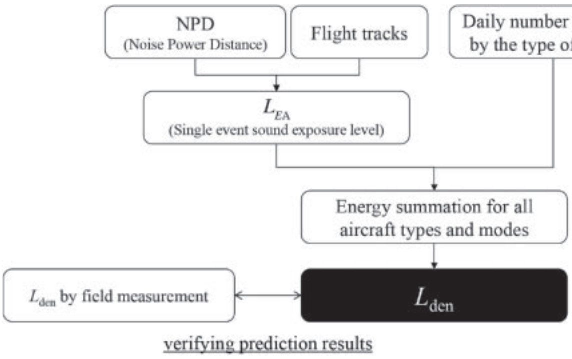


Fig. 1 A flow chart of the prediction method presented in this study.

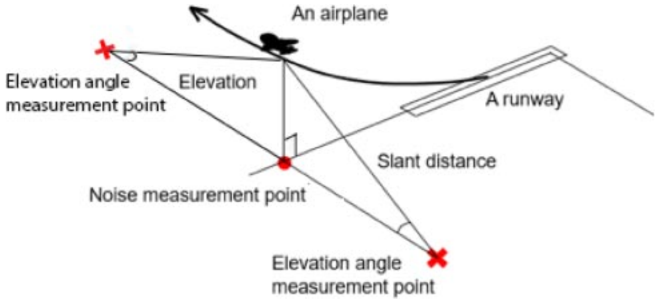


Fig. 2 Diagram of elevation angle and noise measurement.

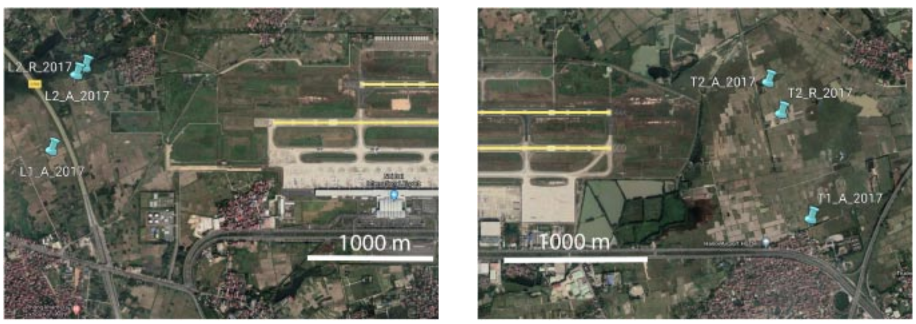
2. PROCEDURE OF THE PREDICTION

2.1. Outline of the Prediction

Figure 1 shows a flow chart of the prediction method presented in this study. Single-event sound exposure levels (L_{EA}) in each aircraft noise event was decided by the NPD data of each aircraft model and flight mode (ex. take-off or landing), and by representative flight path. The value of NPD represents the relationship between the L_{EA} and distances from receiving points under the flight path to the aircraft. Day-evening-night equivalent sound level (L_{den}) was calculated from the L_{EA} values and the number of flight operations. To assess the validity of the predicted noise map, the estimated L_{den} by the INM was compared with the values of field measurement conducted on November 14th in 2017. Therefore, the number of flights used for the prediction was also set based on the flight operation on the day.

2.2. NPD Data

The NPD data installed in INM software was used as a noise source for civil aircraft. For military aircraft, Su-22 manufactured by Sukhoi, which is a single-engine fighter aircraft and has the highest noise level among the main military aircraft in Vietnam, is also operated at NBIA. However, most of the NPD data of Russian-made military aircraft operated in Vietnam are not included in the INM software. The NPD data of Su-22, therefore, was created from the data obtained by the field measurement. Figure 2 shows a diagram of the measurement process for establishing NPD data, which was carried out for two days (November 14th and 15th in 2017) at two sites under the flight path of the NBIA. As shown in Figs. 2 and 3, each measurement site consists of one noise measurement point and two elevation angle measurement points. One site was located about 1.5 km east of the end of the airport runway to obtain the data of take-off sound source, and the other was about 1.5 km west of the end of the airport runway to obtain that of landing sound source. Sound pressure levels in each one-third octave band were sampled at 0.1-second intervals by the sound level meter (RION NL-62) at the noise measurement points. The frequency range of the one-third octave band required to create NPD is 50 Hz to 10 kHz. The sound level meters were installed directly on the ground to limit the effect of wind noise. The elevation angles to estimate slant distance and the one-third octave band levels of aircraft noise were measured simultaneously at the sites. The meteorology data on the two days, which



Landing site

Take-off site

Fig. 3 The position of elevation angle and noise measurement for creating NPD in NBIA (L2_R_2017: noise measurement at landing site, L1_A_2017 and L2_A_2017: elevation angle measurement at landing site, T2_R_2017: noise measurement at take-off site, T1_A_2017 and T2_A_2017: elevation angle measurement at take-off site).

was needed for NPD calculation, including atmospheric pressure (101–101.4 kPa), temperature (302–304 K), and humidity (58–62%) were provided by airport's authority on the basis of every 30 minutes. The wind speed was also recorded at 2–6 mph in the measurement period.

The NPD data of L_{EA} can be created by Eq. (1). The sound exposure level of a single aircraft noise event according to a distance to the noise source, $L_{EA,r}$, was calculated based on a procedure described in a document of ECAC DOC.29 version 2 [3]:

$$L_{EA,r} = L_{EA,0} + (L_{A,Smax,r} - L_{A,Smax,0}) + \beta \log_{10}\left(\frac{D}{D_0}\right) \quad (1)$$

$L_{EA,0}$: A-weighted single event sound exposure level at the reference distance (L_{EA} obtained at NPD measurement site) [dB]

$L_{A,Smax,r}$: Maximum A-weighted sound pressure level according to the distance from a given receiving point to the noise source [dB]

$L_{A,Smax,0}$: Maximum A-weighted sound pressure level at the reference distance ($L_{A,Smax}$ obtained at NPD measurement site) [dB]

D: the distance from the noise source to a given receiving point [m]

D_0: the distance from the noise source to the NPD measurement point [m]

β: coefficient of attenuation by the distance (7.5 for civil aircraft and 6.0 for military aircraft, respectively)

To create the NPD data of L_{EA}, it is necessary to calculate the $L_{A,Smax}$ at a given distance ($L_{A,Smax,r}$), in other words, it is necessary to create the NPD data of $L_{A,Smax}$. The $L_{A,Smax,r}$ can be calculated from the one-third octave band level measured at the site when the A-weighted sound pressure level reached the maximum with considering the geometrical diffusive decay by the distance from D to D_0 and sound attenuation for each one-third octave band level due to air absorption according to ISO 9613-1 [4]. Once $L_{A,Smax,r}$ is determined, $L_{EA,0}$ and $L_{A,Smax,0}$ are the known values obtained at the NPD measurement site, so, $L_{EA,r}$ can be calculated by Eq. (1). Equation (1) means that NPD of L_{EA} attenuates by the slant distance more slowly than that of $L_{A,Smax}$, and this explanation is consistent with the empirical knowledge that the longer the distance, the longer the duration of the noise event. In this study, the coefficient of attenuation by the distance was set at 6.

In the field survey, four take-off noise events and 22 landing noise events of Su-22 were sampled; therefore, the average value of the NPD in each flight mode was applied as the NPD data of L_{EA} of Su-22. Herein, the prediction of L_{den} in the case of applying the NPD data of the alternative fighter aircraft model included in INM was also conducted to compare with the result in the case of using the Su-22 NPD data based on field measurement.

2.3. Flight Path

The flight paths of civil aircraft were set based on the field observation by Automatic Dependent Surveillance-Broadcast (ADS-B). ADS-B is a precise satellite-based surveillance system that continuously tracks the aircraft positions. The flight paths of take-off and landing were classified into seven routes, respectively, based on the collected ADS-B data during the measurement period (Fig. 4). However, ADS-B cannot determine the flight path of military aircraft. Therefore, the flight path of the military aircraft was set to be a straight line in the direction of the runway extension for take-off and landing based on the results of visual observation at the site.

2.4. The Number of Flight Operation

Airport operation data, including flight logs and weather conditions, were provided by the airport managers. Although NBIA is in northern Vietnam, which has four

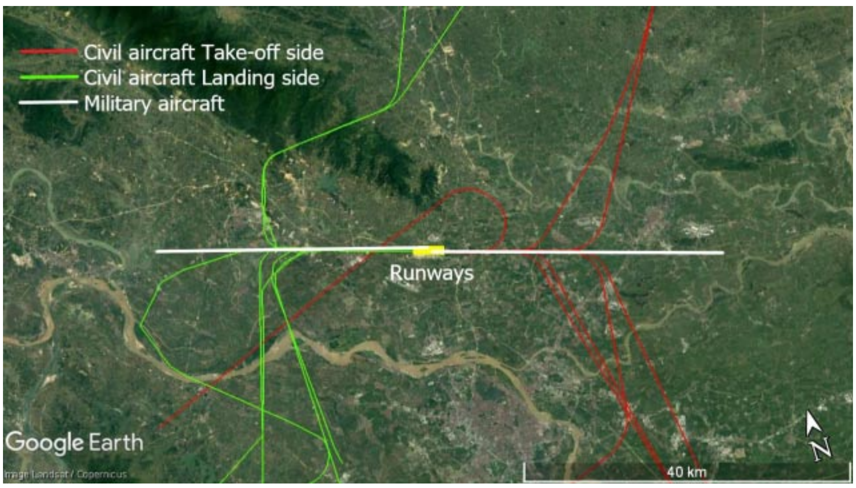


Fig. 4 The representative flight paths around NBIA.

Table 1 Civil and military aircraft types operated in NBIA.

Civil aircraft (November 14th, 2017)					
Type	Departures	Arrivals	Type	Departures	Arrivals
A321	75	71	A332	1	2
A320	53	55	A330	2	2
B789	11	11	B772	2	2
A359	10	10	B777	2	2
AT72	7	7	A319	1	2
A333	4	5	B747-800F	0	1
A332	4	4	E90	1	1
B738	4	4	A330F	1	1
B747	3	4	B777F	1	0
B747-400	3	2	B787	1	1
B773	2	2	B739	1	0
C208	2	2	PC12	0	1
			Total	191	192

Military aircraft (November 14th, 2017)		
Type	Departures	Arrivals
Su-22	8	11
C-17	1	2
Total	9	13

seasons, the flight operation at NBIA is categorized into winter (late October to late March) and summer (in the remaining period) schedules. Runways and flight tracks usage depends on the operation modes and weather conditions, e.g., wind direction. According to the flight logs, the average arrivals and departures a day in NBIA is approximately 400 flights, respectively, as shown in Table 1. The twin-engine jet airliner A320 and A321 manufactured by Airbus occupied the majority of all the flights with a total of 64% of NBIA. About 20 military flight events were measured and recorded during the field measurement conducted in the day.

2.5. Data Collection to Verify the Results of the Prediction

The purpose of assessing the validity of the estimated noise level, field noise measurements were conducted at 11 sites around NBIA (Fig. 5). A sound level meter (RION NL-42) was set up on the rooftop of a house located in each of these sites. At Site A6, however, it was impossible to access the rooftop of the house. The sound level meter was installed on the balcony of the house at the site. As a result, the noise level considerably decreased, possibly up to 10 dB, due to the shielding effect of the building. The data at Site A6, therefore, were excluded from the analysis in the next section.

A-weighted sound pressure levels ($L_{p\mathrm{A}}$) were continuously recorded every 0.1 s for seven successive days. The noise data at each site were compared with flight logs to identify the aircraft events, and then $L_{E\mathrm{A}}$ in each aircraft noise event was calculated from the $L_{p\mathrm{A}}$ recording. After that, L_{den} at each site was calculated by using the $L_{E\mathrm{A}}$ values of all aircraft noise events. The day, evening, and night periods to calculate L_{den} are different between countries, depend on the activity pattern of daily life. In Vietnam, they are defined as the periods from 06:00 to 18:00, from 18:00 to 22:00, and from 22:00 to 06:00, respectively [5].

3. RESULTS

3.1. Prediction Conditions

The three cases of NPD data conditions used in the predictions are described in Table 2. Case 1 is a prediction of civil aircraft noise in NBIA by using INM's NPD. The military aircraft was not considered for the prediction in Case 1. Case 2 is a prediction that added the contributions of military aircraft noise to the estimation of Case 1 by using the NPD data of F-16 as the alternative fighter

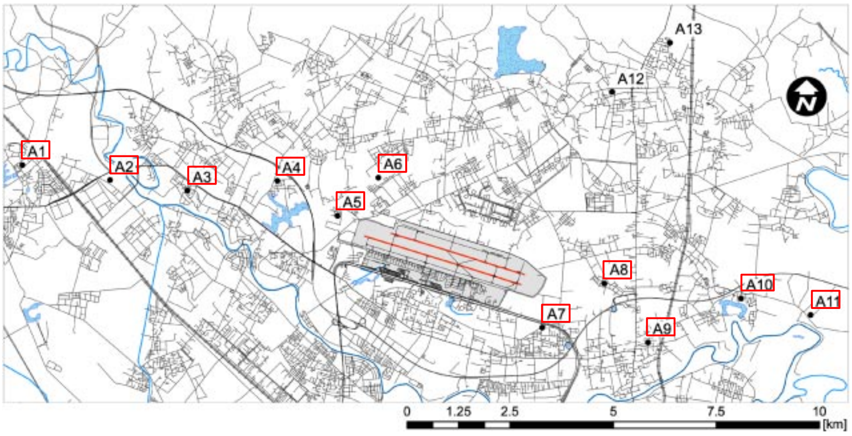


Fig. 5 Map of the field measurement sites in NBIA.

Table 2 The NPD data combinations used in the three cases of calculations.

	NPD for civil aircraft	Military aircraft
Case 1	INM's	(not taken into consideration)
Case 2		F-16 as an alternative aircraft model (INM's NPD data)
Case 3		Su-22 (Measurement-based NPD data)

aircraft model included in INM. Table 3 shows a comparison of the performance data between Su-22 and other military aircraft models, which are included in INM, according to the report by the European Organization for the Safety of Air Navigation [6]. The performance data of F-16 was shown to be the most similar to that of Su-22. It was assumed that F-16 has similar noise emission characteristics with Su-22. The NPD data of F-16 and measurement-based NPD of Su-22 investigated in the present study is shown in Table 4. In the table, A321, which is a representative civil aircraft operated in NBIA, is also shown for the comparison with Su-22 and F-16. In Case 3, the NPD data of military aircraft noise in Case 2 was changed to that of Su-22, which was derived from the field measurement.

3.2. Comparison of Prediction Results

Figure 6 shows the results in Case 1 (only civil aircraft), Case 2 (with military aircraft by INM's NPD: F-16) and Case 3 (with military aircraft by field measured NPD: Su-22); the relation between the predicted L_{den} and measured L_{den} at each site on November 14th in 2017. The consistency between the predicted and the measured values were examined by comparing the root mean square error (RMS). The trend in each case is as follows:

- Case 1: Sites A2 and A9 had relatively similar measured and predicted values, but the measured values at other sites were about 3 dB larger than predicted values.
- Case 2: Sites A2 and A9 remained as accurate as Case 1, and sites A7, A8, A10, and A11 slightly improved.
- Case 3: The differences of L_{den} at the sites located on the take-off side are much less than those in Case 2.

Comparing the result in Case 1 with those in Case 2, it can be seen that the correspondence with measured values is improved by considering military aircraft. The prediction in Case 3 is more consistent with the field measured values than that in Case 2.

4. DISCUSSION

4.1. The Effect of Applying Measurement-based NPD of Su-22

The result in Case 2, with the use of INM's NPD data for military aircraft, F-16, has better correspondence between the prediction and the measurement than that in Case 1. In Case 3, although the correspondence did not change much from Case 2 at some measurement sites, the others that had a much better correspondence than those in Case 2. It is worth noting that the considerable improvement of correspondence was found at Sites A7, A8, A10, and A11, which are all located on the east side of the airport, and the contribution of the take-off noise is large. As is shown in Table 4, the noise levels of military aircraft take-off were remarkably higher than those of civil aircraft. Therefore, including military aircraft noise contribution into the prediction improve the prediction, especially in the take-off side, despite a few flights. From Table 5, the differences of L_{den} between the prediction and the measurement at the take-off side improve 0.5 dB to 1.1 dB in Case 2 compared to Case 1. Furthermore, as is shown in Table 4, because the noise level of Su-22 is larger than that of F-16, the prediction level increase, and the differences with the measurement are much less than in Case 2.

Table 3 Comparison of performance data between Su-22 and other military aircraft.

		AV-8	Hawk	F-16	Su-22
Type		L1J	L1J	L1J	L1J
Wake turbulence category		M	M	M	M
European wake separation re-categorization		Light	Light	Light	Lower Medium
Approach speed categorization		C	C	D	C
Initial climb	Rate of climb (ft/min)	14,500	9,300	55,000	45,000
	Indicated airspeed (kt)	170	145	175	180
Climb to flight level 150	Rate of climb (ft/min)	10,000	7,000	40,000	35,000
	Indicated airspeed (kt)	270	300	300	300
Climb to flight level 240	Rate of climb (ft/min)	10,000	5,000	30,000	20,000
	Indicated airspeed (kt)	270	300	300	300
Cruise	Ceiling flight level	500	500	500	470
	Rate of climb (ft/min)	5,000	3,000	10,000	10,000
	Indicated airspeed (kt)	480	420	480	550
	Mach No.	0.80	0.75	0.86	0.90
Approach	Indicated airspeed (ft/min)	250	250	250	250
Power plant		1 × 85 kN	1 × 23.6 kN	1 × 122.8 kN	1 × 110.3 kN
Maximum take-off weight		11,793	5,100	14,970	19,500

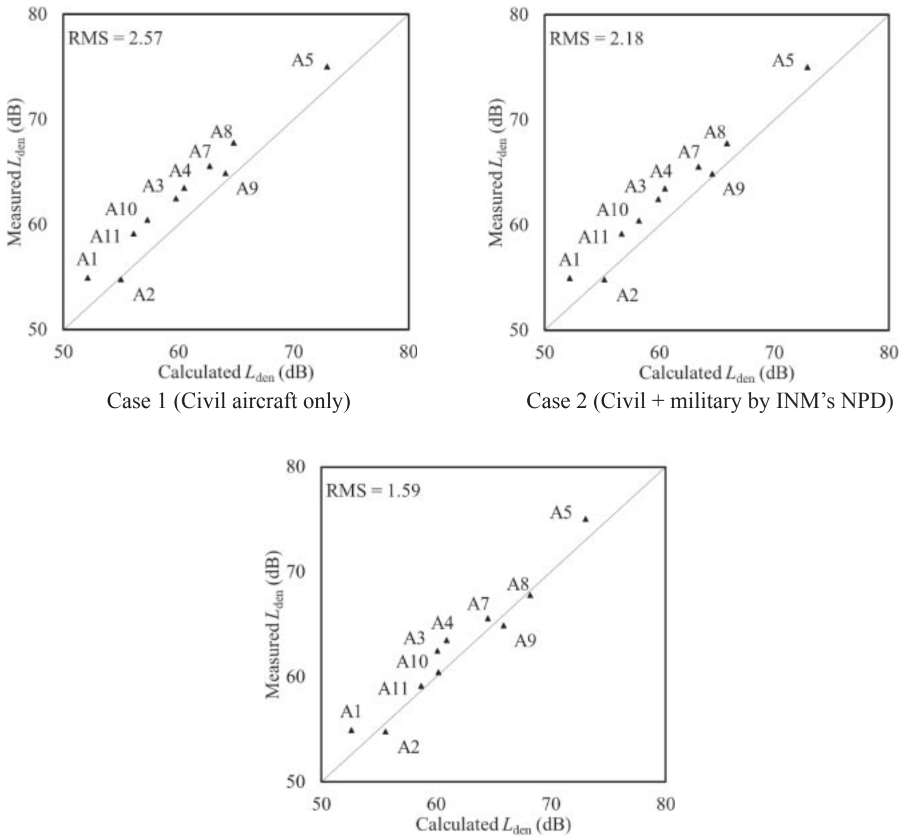
Table 4 Civil and military aircraft types operated in NBIA.

Slant distance (ft)	Su-22		F-16		A321	
	Take-off (dB)	Landing (dB)	Take-off (dB)	Landing (dB)	Take-off (dB)	Landing (dB)
200	127.4	103.8	121.8	101.2	104.1	96.0
400	122.2	100.8	117.0	96.6	100.1	91.4
630	118.7	97.6	113.7	93.3	97.3	88.1
1,000	115.1	94.0	110.1	89.9	94.3	84.6
2,000	109.1	88.3	104.2	84.3	89.3	78.8
4,000	102.1	82.2	97.1	77.9	83.5	72.3
6,300	96.7	77.9	91.5	73.1	79.1	67.4
10,000	90.5	73.5	84.8	67.5	74.0	61.7
16,000	83.4	68.5	76.4	61.3	68.4	55.4
25,000	76.5	63.7	66.1	54.3	62.2	48.6

While the landing noise levels of the military aircraft (Su-22 and F-16) are also higher than that of civil aircraft, the difference is small comparing in the case of take-off noise. Since the number of flights of the civil aircraft is much higher than that of military aircraft, about 20 times, the contribution of civil aircraft noise level into the whole prediction is large, and that of military landing noise is small. Therefore, it can be thought that the differences in L_{den} did not improve for the landing side.

4.2. Agenda toward Aircraft Noise Mapping in Vietnam

In addition to the NBIA, there are several airports where both civil and military aircraft are operated in Vietnam. In general, since the power level of fighter aircraft noise is much higher than that of civil aircraft, a noise map that reflects the contribution of fighter aircraft noises is required. In fact, in this study, the prediction result



Case 1 (Civil aircraft only)

Case 2 (Civil + military by INM's NPD)

Case 3 (Civil + Su-22)

Fig. 6 The comparison of L_{den} between prediction and measurement.

Table 5 The differences of L_{den} between predictions and measurement in each site (Predicted value minus measurement value): Bold characteristics indicates the data at the take-off site.

Site	Case 1 Civil aircraft only [dB]	Case 2 Civil + military by INM's NPD [dB]	Case 3 Civil + Su-22 [dB]
A1	−2.9	−2.8	−2.4
A2	0.2	0.4	0.7
A3	−2.7	−2.6	−2.4
A4	−3.0	−3.0	−2.8
A5	−2.1	−2.1	−1.9
A7	**−2.9**	**−2.2**	**−1.0**
A8	**−3.0**	**−1.9**	**0.3**
A9	**−0.8**	**−0.3**	**1.0**
A10	**−3.2**	**−2.3**	**−0.3**
A11	**−3.1**	**−2.5**	**−0.6**

for civil aircraft only (Case 1) was up to 3 dB lower than the field measurement value.

In Vietnam, there is no information on the noise of military aircraft, and tools to know the NPD, flight route, and the number of flights is required. In this survey, it was possible to collect Su-22 NPD, and it was confirmed that the consistency with the measured values was improved by reflecting them in the calculation of L_{den}. In the present study, NPD for the military airplane was created from frequency characteristics measured in one place. The measurement point was under the take-off side, where the engine output and speed differ depending on the flight distance. It is worthwhile that the prediction accuracy was improved by using measured-based NPD even under these conditions. In the future, it will be necessary to collect NPD data for other military aircraft models. Regarding the flight path, continuous tracking techniques with a camera might be applied for the identification [7]. Regarding the number of flights, it is possible to classify fighter aircraft noise and civil aircraft noise by using time-series data of noise levels. However, when more complicated classification is required, such as distinguishing military aircraft other than fighter aircraft, it is necessary to deal with the aircraft model identification technique based on a continuous recording of frequency characteristics [8].

5. CONCLUSIONS

In this paper, aircraft noise prediction at NBIA in Vietnam was conducted and compared with field measurement values. The results of the calculation of three cases suggested the following:

– It is important to include military aircraft in the prediction (Comparing Case 1 with Cases 2 and 3).
– Because NPD of military aircraft operated in Vietnam is not included in INM, it is necessary to create NPD based on field measurement (Comparing Case 2 with Case 3).

A further study on improving the validity of the estimation is planned and expected to contribute to a reliable method of noise map estimation for aviation environment management in Vietnam and sustainable air traffic development in Vietnam and other Asian countries.

ACKNOWLEDGMENTS

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