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The Okinawa study: an estimation of noise-induced hearing loss on the basis of the records of aircraft noise exposure around Kadena Air Base

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Abstract

Aircraft noise measurements were recorded at the residential areas in the vicinity of Kadena Air Base, Okinawa in 1968 and 1972 at the time of the Vietnam war. The estimated equivalent continuous A-weighted sound pressure level L_{Aeq} for 24 h was 85 dB.The time history of sound level during 24 h was estimated from the measurement conducted in 1968, and the sound level was converted into the spectrum level at the centre frequency of the critical band of temporary threshold shift (TTS) using the results of spectrum analysis of aircraft noise operated at the airfield. With the information of spectrum level and its time history, TTS was calculated as a function of time and level change. The permanent threshold shift was also calculated by means of Robinson's method and ISO's method. The results indicate the noise exposure around Kadena Air Base was hazardous to hearing and is likely to have caused hearing loss to people living in its vicinity.

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1. Introduction

Some areas adjacent to Kadena US Air Base in Okinawa have for the last 40 years been exposed to intense ground noise from the airfield as well as over-flight noise. The noise exposure during the Vietnam War era was so intense that it is hypothesised that it could have caused hearing loss among the local residents. This paper estimates the possibility that hearing loss could occur among people living in the vicinity of the airfield.

2. Noise measurements

2.1. Measurement at Kadena Fire Station in 1968

During the Vietnam War, a few measurements were conducted at the residential areas in the vicinity of Kadena Air Base in 1968 by a local authority and in 1972 by the Defence Facilities Administration Agency of Japan.

The noise measurement in 1968 were done at Kadena Fire Station, next to the fence of the northwest part of Kadena Air Base where the engine-tuning site was and still is positioned (Fig. 1). At that time, the aircraft engines were tuned and tested without any noise insulation facility or barrier at a distance of about 150 m from the residential area. The fact that the local authority dared to measure aircraft noise under the prevailing political situation signifies how the noise was considered unbearable by local people around the base.

A series of measurements were carried out for 1 month in the building, with the windows open. The measurements comprised the time of noise event in a day, maximum sound level in single noise event and the duration of noise exceeding the sound level of 70 dB. Among the several measurements made, continuous measurements that were carried out for a week, from February 12, 1968 were found to be the most suitable to estimate the past noise exposure.

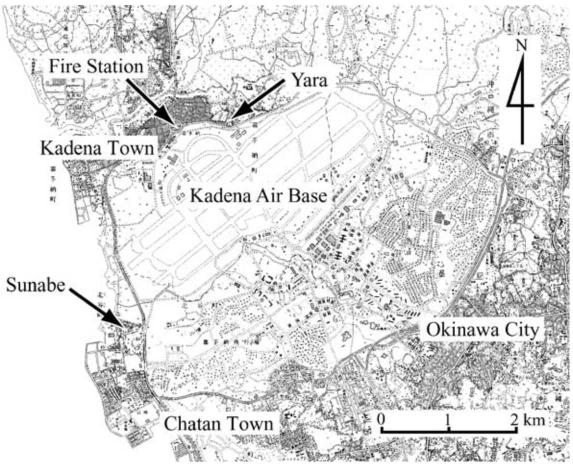

Fig. 1. The Kadena airfield and the area investigated.

Table 1
Noise measurements at Kadena Fire Station

Date	The number of noise events					L_{max} (dB)	Estimated
	0–7 h	7–19 h	19–22 h	22–24 h	Sum		$L_{Aeq,24\,h}$ (dB)
12/Feb/1968	34	44	12	6	96	107	79–86
13/Feb/1968	41	49	24	11	125	107	80–89
14/Feb/1968	28	49	10	5	92	110	83–93
15/Feb/1968	9	25	9	5	48	100	68–73
16/Feb/1968	37	45	13	4	99	104	80–88
17/Feb/1968	41	51	23	16	131	110	79–87
Average	32	44	15	8	99	108	80–88

Table 1 presents the number of noise events for the different hours of a day, the daily maximum sound level, L_{max}, and the estimated range of the equivalent continuous A-weighted sound pressure level for 24 h. Upper limit of the range was obtained on the condition that the time history of the level change is rectangular, i.e. the duration recorded is considered as the duration of the plateau of noise event. The lower limit was obtained on the condition that the plateau of noise event was 10% of the recorded duration. The average of maximum sound level shown in the table is calculated on a power basis.

2.2. *Measurements at Sunabe and Yara in 1972*

In November 1972, during the fierce period of Vietnam War, the DFAA installed monitoring stations at Yara in Kadena Village and at Sunabe in Chatan Village as shown in Fig. 1. Sunabe is the area under the flight paths of aircraft landing and taking off and was suffering from the highest noise exposure in Okinawa. Yara is the area nearest to the engine-tuning and-testing spot. At one of the ends of the runways close to Sunabe, engines were tuned occasionally. The automatic recording of the sound level was carried out every 5 s for 5 months from November 1972 to March 1973.

The monthly maximum sound levels during this period were 120–124 dB at Sunabe and 118–127 dB at Yara. The data were observed in front of local houses when the engine-tuning operation was carried out. Tables 2 and 3 show the statistics of noise indices at Sunabe and Yara. L_{max} and $L_{Aeq,24\,h}$ represent daily maximum sound level and daily equivalent continuous A-weighted sound pressure level. On November 2, the sound level exceeded 110 dB for 3 min, 40 s, and 70 dB for 8.5 hours a day, and the $L_{Aeq,24\,h}$ was 89 dB.

2.3. *Noise recording for 30 h in 1995*

In December 1995, the authors conducted 30 h recording of aircraft noise at several sites around the Kadena and Futenma airfields. The recording was used to determine the temporal pattern of the sound level of aircraft noise, which was found to be triangular, and the relation between

Table 2
Statistics of noise indices at Sunabe in Nov/1972

Statistics	Daily cumulated exposure time (s)					L_{max} (dB)	$L_{Aeq,24h}$ (dB)
	$\geqslant$110 dB	$\geqslant$100 dB	$\geqslant$90 dB	$\geqslant$80 dB	$\geqslant$70 dB		
Maximum	85	1155	3115	8475	17730	124	87
90 percentile	53	736	2369	7879	13952	119	85
Average	16	349	1861	6300	10788	116	83
Minimum	0	40	775	3655	7055	103	78

Table 3
Statistics of noise indices at Yara in Nov/1972

Statistics	Daily cumulated exposure time (s)					L_{max} (dB)	$L_{Aeq,24h}$ (dB)
	$\geqslant$110 dB	$\geqslant$100 dB	$\geqslant$90 dB	$\geqslant$80 dB	$\geqslant$70 dB		
Maximum	220	1560	5850	15265	30645	116	89
90 percentile	40	783	3866	14424	22564	111	87
Average	15	437	2589	10006	16352	109	84
Minimum	0	55	825	4760	7610	103	77

spectrum level at the centre frequency of TTS's critical band and A-weighted sound pressure level of aircraft noise.

3. Risk assessment

3.1. Comparison with noise criteria

The values of $L_{Aeq,24h}$, 83 dB at Sunabe and 84 dB at Yara were higher than the permissible criteria of occupational noise exposure for hearing conservation recommended by the Japan Society for Occupational Health, 80 dB for 24 working hours a day [1]. The criteria is set to prevent hearing loss, less than 20 dB for the most vulnerable test frequency of 4 kHz after prolonged exposure over years. The levels also exceed the 24 h exposure level of 70 dB that the US EPA identifies as the level of environmental noise which will prevent any measurable hearing loss over a lifetime [2]. The results thus strongly suggest that the hearing of local residents could be damaged by the noise from the base.

3.2. Estimation of TTS

A method to computate temporary threshold shift (TTS) is available if the temporal and spectral features of noise exposure are given. The method consists of two stages. One is the critical band theory with respect to TTS, which deals with the spectral aspect of the exposure noise. The other is the application of unit-step-function to simulate the temporal change of the level of exposure noise whereafter the formula of TTS growth is applied to the local steady part of the noise [3].

The sound level of aircraft noise was converted to spectrum level at the centre frequency of TTS's critical band on the basis of 30 h recording of aircraft noise. The spectrum level in relation to the A-weighted sound pressure level of aircraft noise is illustrated in Fig. 2. The solid line in the figure has a slope of 45° with the section of mean difference between spectrum level and sound level on power basis. The dotted lines indicate the upper and lower limits of the ranges of 3 dB at vertical distance from the solid line. The relation between the two levels depends on various factors such as the type of aircraft, the condition of operation and so forth. However, it would be safe to consider that the conversion of sound level to spectrum level in the past noise exposure drops within the range of the dotted lines. The upper and lower lines give the possible maximum and minimum estimation of TTS, respectively, for the same sound level.

The time history of sound level during 24 h was estimated from the recorded data at Kadena Fire Station in 1968 as illustrated at the top of Fig. 3. The temporary threshold shift due to the aircraft noise exposure was calculated from the time history of the critical band level by means of the method of TTS calculation and the result is presented as the lower part in the figure. The estimations of TTS are conducted as to the upper limit of the range and the lower limit of the level conversion presented in Fig. 2 and drawn by a solid curve and a dashed curve in Fig. 3.

The maximum TTS in 24 h estimated above as a function of test frequency is plotted in Fig. 4. There is a clear c^5-dip of TTS and maximum TTS in excess of 20 dB at 4 kHz. As this is an average estimation of TTS for exposed populations, a higher TTS could be present for some highly susceptible individuals.

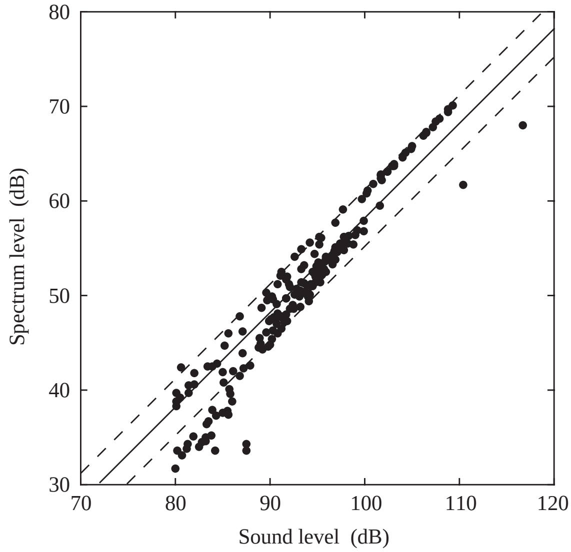

Fig. 2. Spectrum level at 4 kHz vs. sound level of aircraft noise.

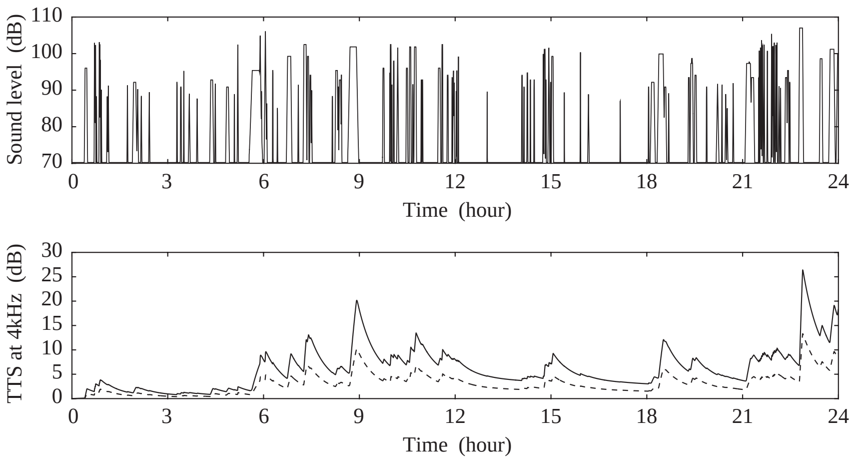

Fig. 3. Noise events and estimated TTS at 4 kHz (Kadena Fire Station, 13 February 1968).

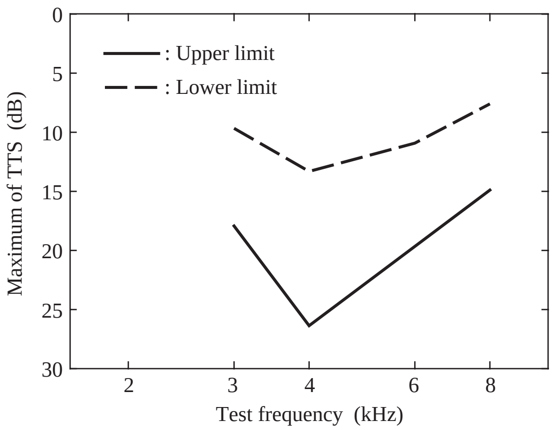

Fig. 4. Maximum of estimated TTS.

Since temporary threshold shift measured at 2 min after the cessation of daily noise exposure is regarded as approximately equal to the permanent threshold shift induced by habitual exposure to the same noise over 10 years [4], the results of the TTS estimation suggest that there is a possibility that the noise exposure could have induced local residents' permanent hearing loss in the vicinity of Kadena Air Base.

3.3. Robinson's method

Robinson proposes a formula giving noise-induced permanent threshold shift, NIPTS, due to prolonged noise exposure as a function of the level of noise exposure which he calls Noise Immission Level, exposure years, age, sex and test frequency of audiometry [5]. The Noise

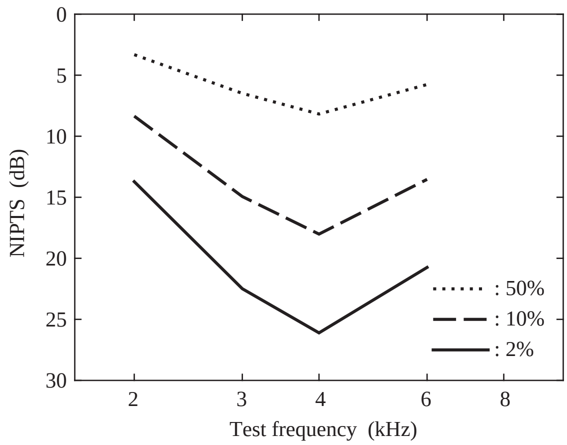

Fig. 5. Estimated NIPTS by Robinson's method (Sunabe, $L_{\mathrm{Aeq,24\,h}} = 83$ dB, 10 years).

Immission Level is expressed by means of average of sound level on power basis over a year. His method has an advantage in the point that it gives the distribution of the NIPTS, while other workers' methods give mean and some values of deviation of NIPTS. This study applied Robinson's method to estimate the NIPTS due to the aircraft noise exposure around the airfield with the data of measurement obtained in 1972.

Fig. 5 shows the 2, 10 and 50 percentiles of NIPTS as a function of test frequency estimated by means of Robinson's method under the condition of noise exposure to 83 dB in L_{Aeq}, which is Sunabe's noise level, for 10 years. It should be noted that 2 percentile of NIPTS is over 20 dB at the test frequency of 4 kHz.

3.4. ISO method

The International Standardization Organization (ISO) method for estimating noise-induced permanent threshold shift is based on the concept of equal energy rule and gives the hearing level of an individual at any percentage in the population based on the exposure noise level and the exposure duration [6]. The present study assumes the exposure noise level to be 83 dB and 86 dB of $L_{\mathrm{Aeq,24\,h}}$ (the average value observed at the Sunabe in 1972 and its upper limit of the 3 dB range) and the exposure duration to be 10 years.

The estimation of NIPTS by means of ISO's method is based on 8 working hours a day and 5 working days a week and needs a 5 dB correction for the method to apply for the exposure duration of 24 hours a day.

Figs. 6 and 7 illustrate the NIPTS estimated for the noise exposure of $L_{\mathrm{Aeq,24\,h}} = 83$ and 86 dB at Sunabe. Three curves in the figures indicate 5, 50 and 95 percentiles of NIPTS eliminating the contribution of presbyacusis. Though the 95 percentile of NIPTS at 4 kHz is less than 10 dB one can see that the 50 percentile of NIPTS exceeds 15 dB and 5 percentile does 20 dB in Fig. 7. This suggests that large individual differences exist in terms of noise susceptibility. Comparison of the two figures shows that the 3 dB difference of exposure noise level results in 7 dB difference of

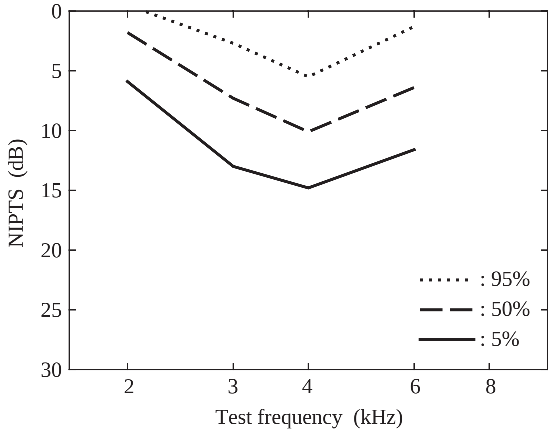

Fig. 6. Estimated NIPTS by ISO 1999 (Sunabe, $L_{Aeq,24\,h} = 83\,dB$, 10 years).

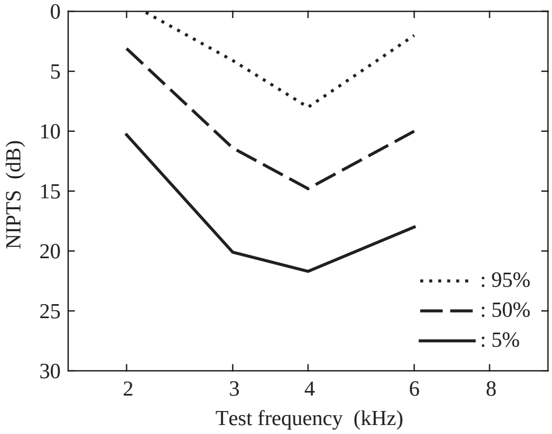

Fig. 7. Estimated NIPTS by ISO 1999 (Sunabe, $L_{Aeq,24\,h} = 86\,dB$, 10 years).

NIPTS at 5 percentile. This suggests that the risk of hearing loss sharply increases with the increase of exposure noise level.

The results suggest that there may be some residents in the vicinity of the Kadena field who suffer from hearing loss due to the noise exposure from aircraft landing and taking off.

4. Conclusions

The state of past noise exposure estimated according to a few measurements at the residential area in the vicinity of Kadena Air Base in 1968 and 1972 during the Vietnam War is found as high as the permissible criteria for hearing conservation for eight working hours a day recommended by the Japan Society for Occupational Health, which indicates, since the criteria adopt Kryter's limit as the fence of hearing, local people having lived in the area could suffer from hearing loss induced by noise exposure of up to 20 dB at 4 kHz. The average temporary threshold shift (TTS) calculated from the time history of sound level during 24 h of the measurement conducted in 1968 indicates the maximum TTS which occurred during the 24 h exceeding 20 dB at 4 kHz. Noise-induced permanent threshold shift (NIPTS) calculated by means of Robinson's method is for 10 percentile of NIPTS to be about 20 dB and estimation of NIPTS on ISO basis gives 50 percentile of 10–15 dB and 5 percentile of 15–22 dB at 4 kHz for 10 years of exposure.

The analyses presented here, based on actual noise recordings in 1968 and 1972 strongly suggest the existence of the risk of hearing loss among the residents in Kadena Air Base's vicinal area due to the intense noise exposure for the past 35 years.

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