# Chapter 9

# Hearing loss

## 9.1 Estimation of noise induced hearing loss on the basis of the record of past noise exposure

Noise-induced hearing loss is considered to become a detectable permanent hearing loss through the repetition of temporary hearing loss and its recovery that starts an undetectable infinitesimal permanent hearing loss and its accumulation.

The past noise exposure during the Vietnam War era was estimated in the previous section using measurements recorded at the residential areas in the vicinity of Kadena airfield in 1968 and 1972. The estimated WECPNL was around 105, and the equivalent continuous sound pressure level, $L_{\mathrm{Aeq}}$, for averaging time of 24 hours came to 83 dB. These values are serious when compared with the permissible criteria of occupational noise exposure for hearing conservation recommended by Japan Society for Occupational Health which is 80 dB for 24 working hours a day. The criteria is provided in the expectation that average hearing loss can be controlled after prolonged exposure of over years under 20 dB for the test frequency of 4 kHz.

### 9.1.1 Estimation of TTS due to aircraft noise

A method of computation of average temporary threshold shift (TTS) (Takagi K, Hiramatsu K & Yamamoto T; 1988) is available if the temporal and spectral features of noise exposure are given; in its turn, permanent average hearing loss can be estimated to a certain extent from past measurement of noise exposure.

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

**Table 9.1** Critical band width in dB and its center frequency (Yamamoto *et al.*; 1970)

| Test frequency (kHz) | Center frequency (Hz) | Bandwidth and its 95% CI (dB) |
|---|---|---|
| 0.5 | 490 | 21.3 ± 1.5 |
| 0.8 | 600 | 23.8 ± 1.3 |
| 1 | 730 | 23.8 ± 1.6 |
| 1.5 | 1010 | 24.0 ± 1.3 |
| 2 | 1400 | 26.0 ± 0.8 |
| 3 | 2620 | 29.7 ± 0.9 |
| 4 | 3040 | 30.5 ± 0.8 |
| 6 | 3840 | 29.9 ± 1.0 |
| 8 | 4950 | 33.3 ± 0.8 |

**Table 9.2** Constants included in the equation for TTS (Ito *et al.*; 1987)

| Frequency (Hz) | $a$ (dB) | $b$ (dB$^{-1}$) | $T_1$ (min) | $m$ (–) | $T_2$ (min) |
|---|---|---|---|---|---|
| 500 | 0.016 | 0.102 | 15.7 | 2.00 | 105.0 |
| 800 | 0.037 | 0.101 | 62.0 | 1.77 | 257.4 |
| 1000 | 0.115 | 0.090 | 94.1 | 1.62 | 617.3 |
| 1500 | 1.347 | 0.054 | 44.8 | 1.47 | 352.0 |
| 2000 | 0.063 | 0.102 | 13.4 | 1.61 | 179.9 |
| 3000 | 0.118 | 0.103 | 41.8 | 1.16 | 182.7 |
| 4000 | 0.106 | 0.114 | 31.8 | 1.04 | 337.6 |
| 6000 | 0.261 | 0.098 | 14.8 | 1.07 | 412.0 |
| 8000 | 0.110 | 0.112 | 17.0 | 1.41 | 458.6 |

change of the level of exposure noise and the formula of TTS growth is applied to the local steady part of the noise.

The critical bandwidth and centre frequency of TTS at 9 test frequencies are given in Table 9.1. The formulae of TTS growth are given by the following equation, the constants in the equation are shown in Table 9.2.

$$TTS_\tau(S,t) = TTS_0(S,t+\tau) - TTS_0(S,\tau),$$
$$TTS_0(S,t) = a\exp(bS)\frac{1-\exp(-t/T_1)}{1+m\exp(-t/T_2)}$$

The unit-step-function method expresses the temporal pattern of the level fluctuation of the exposure noise in Figure 9.1 by means of the unit step function $U(t)$ ($= 0$ for $t \leq 0$, $= 1$ for $t > 0$), as follows;

$$S_1[\mathrm{U}(t) - \mathrm{U}(t-T_1)] + S_2[\mathrm{U}(t-T_1) - \mathrm{U}(t-T_1-T_2)] + \cdots$$
$$+ S_i[\mathrm{U}(t-T_1-T_2-\ldots-T_{i-1}) - \mathrm{U}(t-T_1-T_2-\ldots-T_i)] + \cdots$$

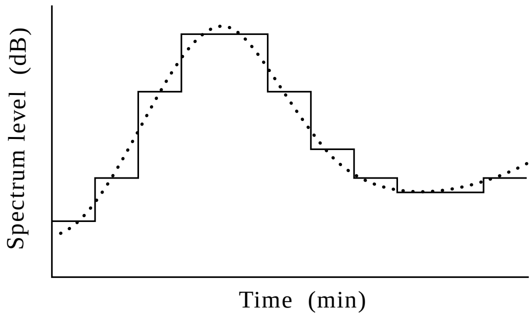



**Figure 9.1** Temporal pattern of the level fluctuation and aproximation by unit step functions.

Here $S_i$ is the level of the exposure noise. With this supposed to be the input, the output then is

$$
\begin{aligned}
&f_{S_1}(t) - \mathrm{U}(t - T_1) f_{S_1}(t - T_1) \\
&+ \mathrm{U}(t - T_1) f_{S_2}(t - T_1) - \mathrm{U}(t - T_1 - T_2) f_{S_2}(t - T_1 - T_2) + \cdots \\
&- \mathrm{U}(t - T_1 - T_2 - \cdots - T_i) f_{S_i}(t - T_1 - T_2 - \cdots - T_i)
\end{aligned}
$$

The notation $f_{S_i}(t)$ denotes *TTS* produced by steady state noise at the level $S_i$.

The time history of sound level during 24 hours is estimated from the recorded data in 1968 and 1972, and the sound level is converted into the critical band level for the test frequency using the results of spectrum analysis of military aircraft noise. The maximum temporary threshold shift due to aircraft noise exposure at that time is calculated from the time history of critical band level by means of the method described above.

The result of calculation is presented in Figure 9.2. It indicates the noise exposure around Kadena airfield causes TTS in excess of 20 dB. This is an average estimation for the exposed populations and further hearing loss could be possible for some highly susceptible individuals.

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 (Glorig *et al.*; 1961). There should be some possibility that the noise exposure in the vicinity of Kadena Air Base might cause the residents permanent hearing loss.

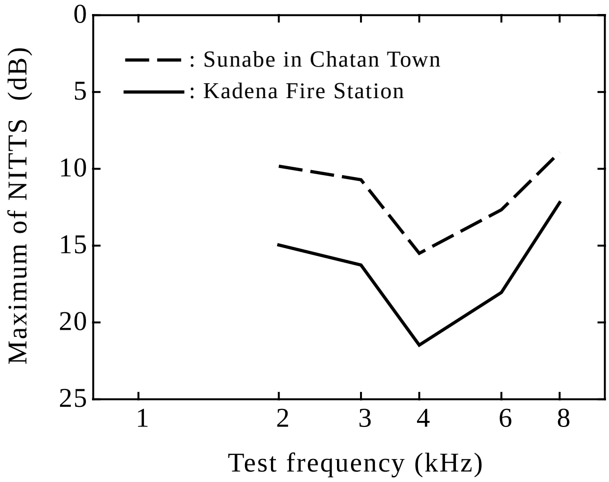



**Figure 9.2** Maximum of calculated NITTS.

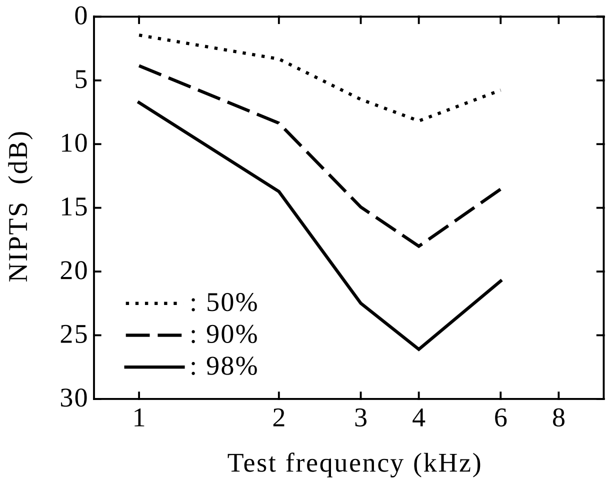



**Figure 9.3** Percentiles of calculated NIPTS.

### 9.1.2 Estimation of NIPTS due to aircraft noise

Robinson among other workers who have proposed methods to estimate permanent hearing loss due to prolonged noise exposure proposes a method to give the percentile of the subjects suffering from noise induced hearing loss (Robinson; 1971). Noise induced permanent threshold shift (NIPTS) due to the noise exposure observed around KAB is calculated according to his method. Note that his method gives comparatively conservative calculation.

Figure 9.3 shows the NIPTS estimated by Robinson's method with 83 dB in $L_{\text{Aeq}}$ for 10 years. In the figure, 50, 90 and 98 percentiles of NIPTS are illustrated as functions of test frequency. The 98 percentile of NIPTS is over 20 dB at the test frequency of 4 kHz.

The results of the calculation of possible hearing loss strongly suggest that there exist some residents in the vicinity of Kadena Air Base who suffer from hearing loss due to the noise exposure from aircraft landing and taking off on the runways of Kadena Air Base.

## 9.2 Hearing tests

### 9.2.1 Primary test

Hearing test was conducted three times from May 1996 to July 1998, at three wards in Chatan Town and Kadena Town, where WECPNL ranged from 85 to 95 and more. The subjects to receive the test were limited to the individuals aged between 25 and 69 years inclusive. The number of residents living in the area to receive the test was 2,035.

#### Inquiry

Before going through audiometry, subjects were asked about hearing, tinnitus, otological anamnesis, past experience of noise exposure in occupation, service and/or hobbies.

#### Audiometry

Tests were carried out by an experienced medical researcher and a trained clinical technician of Otorhinolaryngology Department of Okinawa Chubu Hospital in audiometric booths (DANA Japan, SILENT CABIN) installed in public halls using two audiometers (Rion, AA-67N, AA-62). The public halls are sound insulated on the basis of the DFAA's mitigation programme around military bases. The sound pressure levels of the background noise measured in the booths were under 30 dB. Hearing levels of the subjects were measured by means of ascending method of limits with 5 dB step at 7 test frequencies of 0.5, 1, 2, 3, 4, 6, and 8 kHz.

**Results**

Three hundred and forty three individuals received the test. They were 137 males and 206 females. Among them, 40 individuals who were judged to have possible noise induced hearing loss were sent to Okinawa Chubu Hospital as subjects for a secondary examination held at the Otorhinolaryngology Department. In the selection of the 40 individuals, those having medical history of chronic tympanitis and/or occupational noise exposure are excluded and in the judgement of noise induced hearing loss the hearing levels of the individuals are adjusted for presbyacusis using the hearing levels presented in ISO 7029-1984(E).

### 9.2.2 Secondary test

In the secondary test are conducted pure tone audiometry with 1 dB step at test frequencies of 0.125, 0.25, 0.5, 1, 2, 3, 4, 6 and 8 kHz, Short Increment Sensitivity Index (SISI) test using the sensation level of 20 dB at every test frequency, tympanometry by means of impedance audiometer (RION, RS-20) and audioscan audiometry by means of the device (ESSILOR, Audioscan) with the frequency scanning speed 20 s/oct.

Hearing losses are broadly classified as follows;

1) Conductive Hearing loss, caused by impediments to the external auditory meatus, tympanic membrane or the middle ear;
2) Sensorineural Hearing Loss, caused by impediments to the inner ear or auditory nerve;
   - a: Cochlear Hearing Loss, caused by impediments to the cochlear, especially the inner and outer hair cells and the stria vascularis;
   - b: Retrocochlear Hearing Loss, caused by impediments to auditory nerve and its vast network of central connections within the brainstem.

Since noise induced hearing loss is sensorineural hearing loss, otological examinations of those selected from the first examination were conducted to confirm that their hearing losses were the type of sensorineural hearing loss.

First, the external and middle ears were checked by visual inspection of tympanic membrane and tympanometry. Secondly, air-bone gap of hearing acuity was checked; whether hearing losses observed by air conduction and bone conduction are equal within the margin of measurement error. From the above examination, the subjects' hearing losses were judged non-conductive. Thirdly, SISI test was conducted in order to check for inner ear hearing loss. The subjects showing positive recruitment phenomena, under Jerger's classification, are presumed to have cochlear hearing loss, but no retrocochlear hearing loss. Audiograms of a few subjects suggest they have more progressive hearing loss judging from a dip at higher frequencies.

Thus 12 subjects are chosen, 10 from Chatan Town and 2 from Kadena Town, who have a decline of hearing ability in the frequency range of 3 to 6 kHz, which strongly suggests the hearing losses are due to excessive noise exposure. In Table 9.3 are tabulated the results of hearing tests of the 12 individuals whose audiograms are presented in Figure 9.4. Hearing level by pure tone audiometry is plotted with open circle and cross. Solid line and broken line show the results of audioscan audiometry, and arrows indicate the 90 percentile of presbyacusis defined by ISO 7029-1984 (E): Database A (screened population).

### 9.2.3 Causation between hearing loss and aircraft noise

The result of hearing test alone cannot specifically determine that aircraft noise is the direct cause of their hearing loss. The following 7 reasons can be raised why their hearing losses are likely to be due to the aircraft noise from Kadena Air Base.

#### 1) Audiogram

As a typical pattern of audiogram of noise induced hearing loss $c^5$-dip and its progressive pattern are observed. Recruitment positive is another symptom to support the diagnosis.

#### 2) Geographical concentration

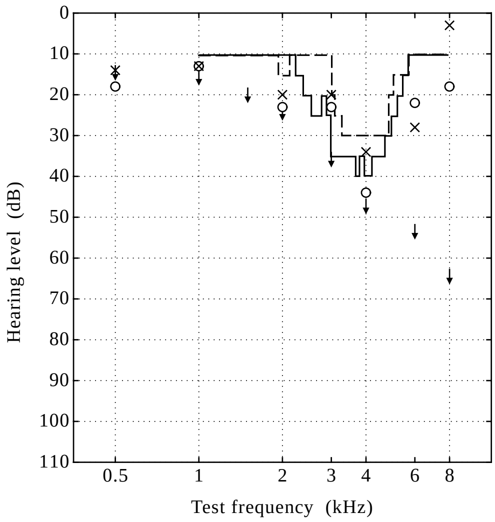
The individual judged noise induced hearing loss are concentrated the vicinal area of the base. The 12 subjects dwell in the closest part in the ward to either of the runways of Kadena Air Base. In Figure 9.5 are plotted the locations of the residences of the subjects living in Sunabe relative to the base. In the

**Table 9.3** Twelve cases of the sensorineural hearing loss in which the aircraft noise exposure seems to be primary cause.

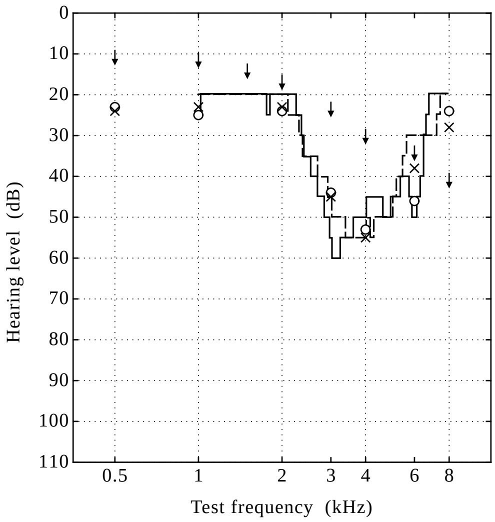
| No. | Sex | Age | WECPNL by DFAA | Year of residence | Anamnesis[1)] | Noise exposure[2)] | Inspection of eardrum |
|---|---|---|---|---|---|---|---|
| 1 | Male | 57 | 95–100 | 40 | None | None | Normal |
| 2 | Male | 47 | 90–95 | 19 | None | None | Normal |
| 3 | Male | 57 | 95–100 | 40 | None | None | Normal |
| 4 | Female | 52 | 95–100 | 39 | None | None | Normal |
| 5 | Male | 48 | 95–100 | 32 | None | None | Normal |
| 6 | Male | 68 | 90–95 | 21 | None | None | Normal |
| 7 | Male | 44 | 95–100 | 40 | None | None | Normal |
| 8 | Male | 59 | 95–100 | 35 | None | 3) | Normal |
| 9 | Male | 63 | 90–95 | 38 | None | None | Normal |
| 10 | Male | 64 | 90–95 | 43 | None | None | Normal |
| 11 | Male | 68 | 85–90 | 40 | None | None | Normal |
| 12 | Male | 33 | 90–95 | 33 | None | None | Normal |

| No. | Tympanometry | Air-bone gap | SISI test (L/R) 1 kHz | SISI test (L/R) 4 kHz | Hearing level (dB) R–4 kHz | Hearing level (dB) L–4 kHz |
|---|---|---|---|---|---|---|
| 1 | A[4)] | None | +−/− | +/+ | 44 | 34 |
| 2 | A | None | −/− | +/+ | 53 | 55 |
| 3 | A | None | −/− | +/+ | 48 | 53 |
| 4 | A | None | −/− | +/+− | 29 | 51 |
| 5 | A | None | +/− | +/+ | 57 | 58 |
| 6 | A | None | −/− | +/+ | 75 | 75 |
| 7 | A | None | −/− | +/+ | 55 | 55 |
| 8 | A | None | +/− | +/+ | 68 | 95 |
| 9 | A | None | −/− | +/+ | 65 | 63 |
| 10 | A | None | −/− | +/+ | 67 | 64 |
| 11 | A | None | +−/− | +/+ | 46 | 52 |
| 12 | A | None | −/− | +/+ | 55 | 47 |

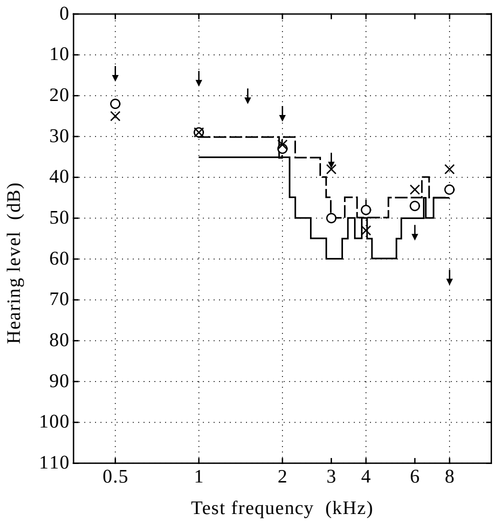
1) Disease possibly causing hearing loss
2) Occupational noise exposure
3) Watchman in the base (Sunabe) for a few years around 56 years old
4) Normal (No abnormality in the sound conductive system of the middle ear)



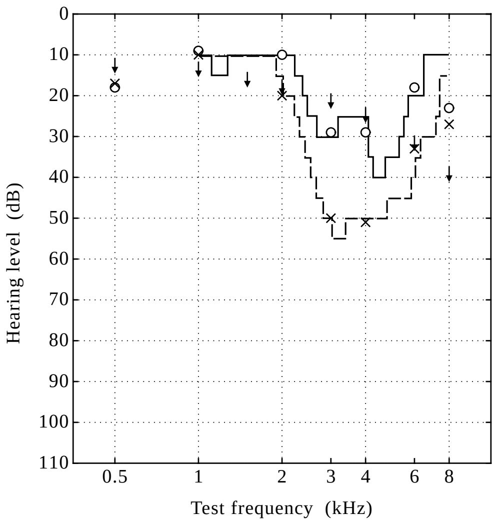

(a) Case 1.




(b) Case 2.



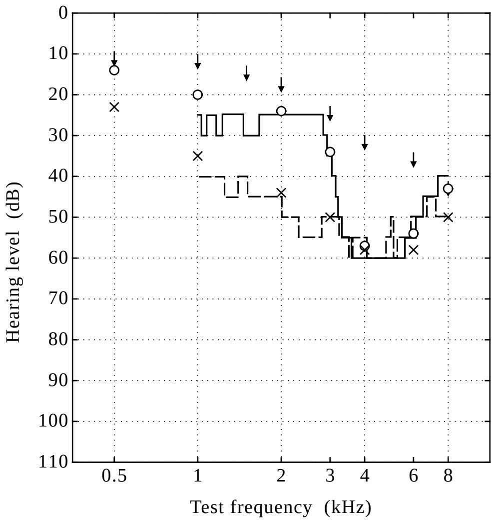

(c) Case 3.



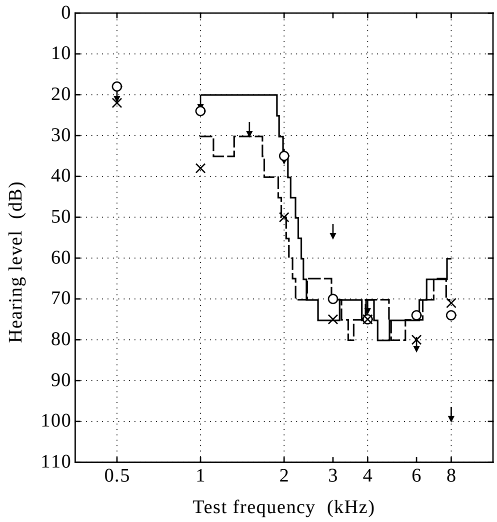

(d) Case 4.

**Figure 9.4** Audiograms of the twelve cases; (1) No. 1–4.

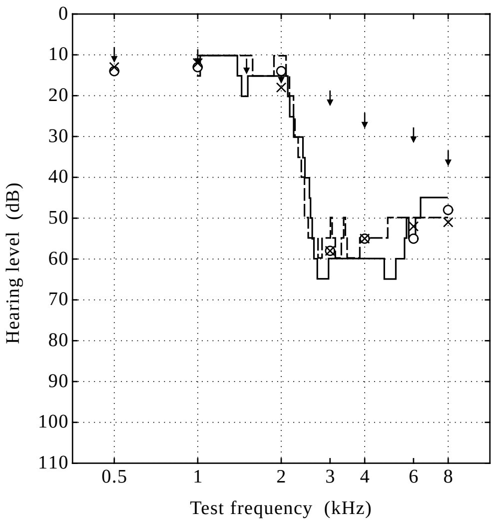
Hearing level by pure tone audiometry is plotted with open circle and cross. Solid line and broken line show the results of audioscan audiometry, and arrows indicate the 90 percentile of presbyacusis defined by ISO 7029-1984 (E): Database A (screened population).



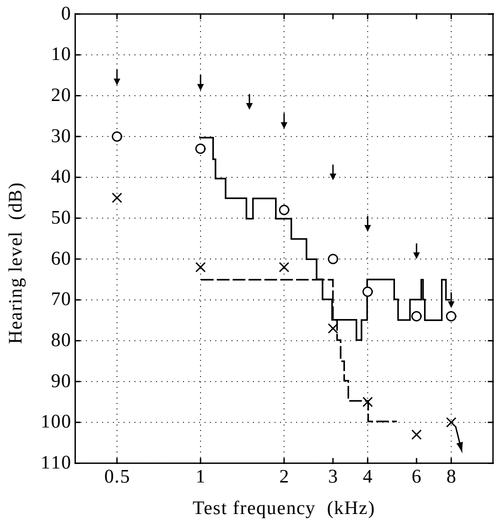

(e) Case 5.




(f) Case 6.



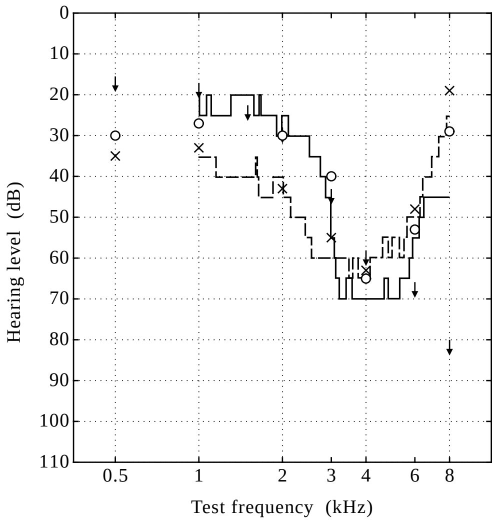

(g) Case 7.



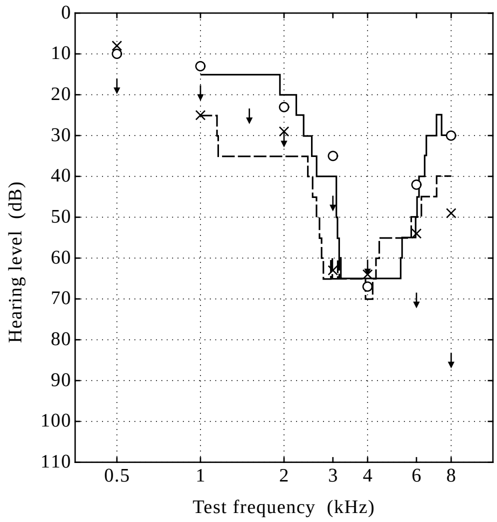

(h) Case 8.

**Figure 9.4** Audiograms of the twelve cases; (2) No. 5–8.

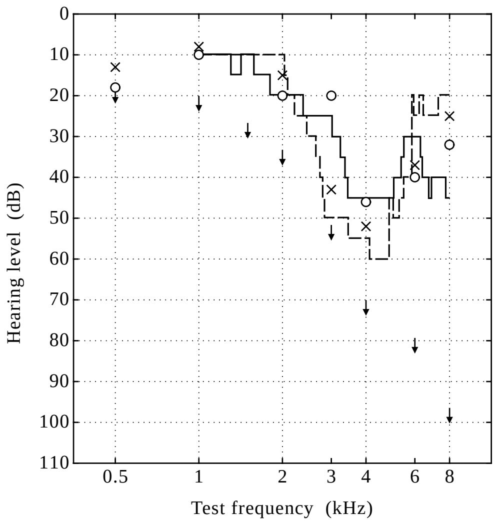
Hearing level by pure tone audiometry is plotted with open circle and cross. Solid line and broken line show the results of audioscan audiometry, and arrows indicate the 90 percentile of presbyacusis defined by ISO 7029-1984 (E): Database A (screened population).



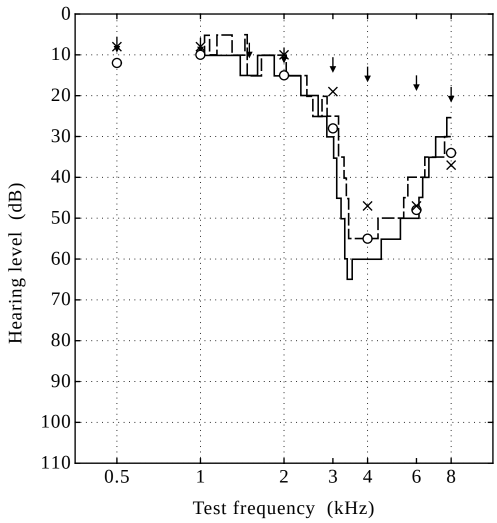

(i) Case 9.




(j) Case 10.




(k) Case 11.




(l) Case 12.

**Figure 9.4** Audiograms of the twelve cases; (3) No. 9–12.

Hearing level by pure tone audiometry is plotted with open circle and cross. Solid line and broken line show the results of audioscan audiometry, and arrows indicate the 90 percentile of presbyacusis defined by ISO 7029-1984 (E): Database A (screened population).

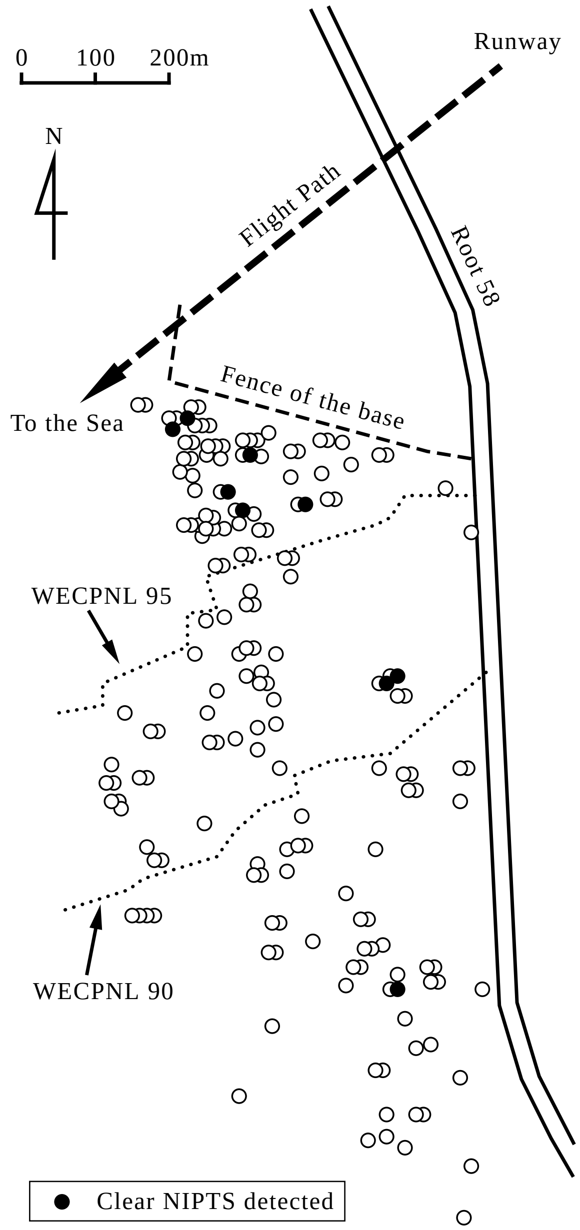



**Figure 9.5** Locations of the homes of the residents who received the hearing test in Sunabe, Chatan Town.

map circles indicate the individuals who went through the hearing test, and among them 9 individuals over 40 years of age were judged to suffer from noise induced hearing loss. There resided 6 individuals in the area of WECPNL over 95, 2 in WECPNL 90–95 and 1 in WECPNL 85–90. Statistical test tells that the increasing trend of the number of individuals having NIPTS with the increase of WECPNL is significant ($p = 0.0402$, one-tailed Mantel extension method with exact test).

### 3) Intense noise exposure

Noise exposure past and present is extremely intense so as to be comparable to damage risk criteria for occupational noise exposure.

### 4) Estimated NITTS/NIPTS

The NITTS at 4 kHz estimated on the basis of the past noise exposure reaches about 20 dB on average and the NIPTS at 4 kHz of one chance in ten individuals is calculated to be about 20 dB.

### 5) Occupational noise exposure

The examiners interviewed the subjects to confirm that they had not experienced repeated intense noise exposure at their residence or workplace other than aircraft noise that might have caused their hearing loss.

### 6) Long term of residence

The individuals had resided in the area for 19 to 43 years.

### 7) High odds ratio for subjective hard of hearing

In the THI questionnaire besides the 130 THI questions was included a question asking if she/he had hard of hearing. Result of the analysis by means of logistic regression model is presented in Figure 9.6. Open circles indicate the odds ratios adjusted by age, sex, occupation and interaction of age and sex with 95% confidence intervals. It is clearly shown that the residents living in the area with WECPNL over 95 appeals hard of hearing and the increase of odds ratio is statistically significant.

These seven reasons strongly supports one to draw a conclusion that the cause of the individuals' hearing losses are most likely the exposure from the past to the present or a certain period in the past to the intense noise from aircraft take-off, landing and tune-up on Kadena Air Base.

## References

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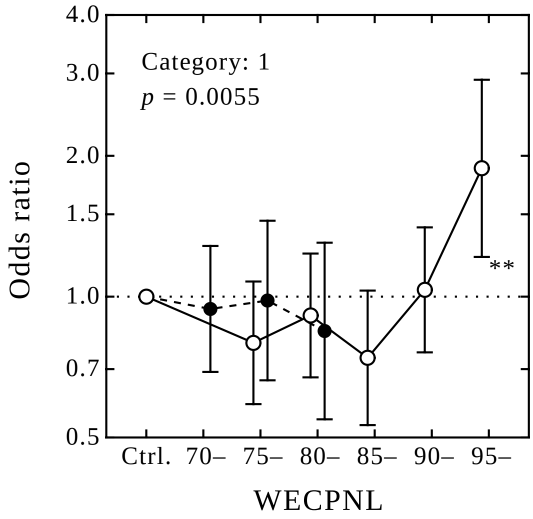


**Figure 9.6** Odds ratio *vs.* WECPNL on subjective hard of hearing.

Takagi K *et al.* (1988), Prediction of noise-induced temporary threshold shift, J Sound Vib 127, 513–519.

Yamamoto T, Takagi K, Shoji H & Yoneda H (1970), Critical band with respect to temporary threshold shift, J. Acoust. Soc. Am. 48, 978–987.

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