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Determination of Noise Exposure around an Airport

By

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Summary: This paper presents a study of drawing the noise exposure contour around an airport. The contour was figured out from the measured data obtained in the vicinity of Osaka Airport. It is compared with the calculated contour based on the data of FAA, the specified flight paths and the scheduled operations similar to those of the period of measurements.

The methods of determination of PNdB, duration and tone corrections are also mentioned together with the relation between PNdB and dB(D) or dB(A).

I. INTRODUCTION

With the rapid increase of air traffic demands, it is now the international tendency that aircraft noise has been a serious social problem for the residents living around airports, and has been growing a great obstacle in the development of air transportation. In Japan, in order to reduce and prevent aircraft noise, the Law concerning the Prevention of Hazards by Aircraft Noise around Public Airports was established in 1967, however, recently residents in the areas around airports are strongly requesting measures for reforming and improving the preservation of environments.

For the purpose of setting up measures for environment preservation, a survey of the area around Osaka International Airport was conducted in compliance with the procedures, as adopted by the recent ICAO Special Meeting on Aircraft Noise. The outline of its result is mentioned.

II. PURPOSE OF SURVEY

The purposes of the survey were (a) to calculate an index number to indicate the effects of noise exposure at various places around the airport and to draw a noise exposure contour diagram, and (b) to set up a land use program that would be compatible with aircraft noise.

The survey was done on the following items:

(1) Determination of EPNL (Effective Perceived Noise Level)

(a) Calculation of PNdB

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Method of analysis, relationships between PNdB and db(D) or dB(A)
(b) Pure tone correction
(c) Duration correction
(2) Calculation of ECPNL (Equivalent Continuous Perceived Noise Level) by measurements
(3) Flight paths analysis
(4) The program for the drawing of ECPNL contour
(5) Predicted noise exposure contour by basic data
(6) Drafting of the land use program

III. Survey and Observation

The survey of noise on areas around Osaka International Airport was carried out in March and August, 1970, and besides February, 1971 at 170 points. Of

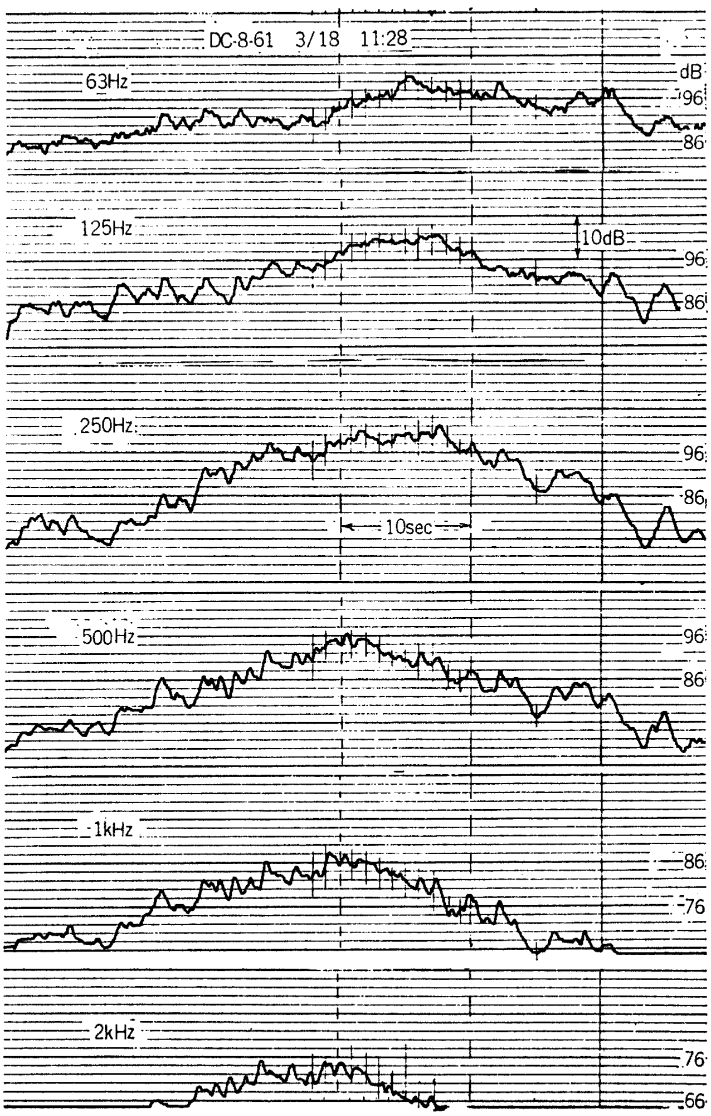


Fig. 1. Time pattern of flyover noise (octave bands).

those, studies on calculation of PNdB, duration correction and tone correction were made for several typical points, by magnetic recording. For the remaining points, measurements were performed for 10 to 12 hours by recording the sound level, and calculated the ECPNL. The Osaka International Airport is the center of the domestic airway network, of which flight frequencies amount to about four hundreds.

(1) Calculation of PNdB

The PNdB can be determined by analyzing and calculating noisiness, noy for each frequency band. Figure 1 shows the time pattern of the octave band noise of DC-8 upon take off. As can be seen from this figure, it would be realized that the calculation of the maximum PNdB from the maxima of the analyzed band pressure levels, could result in overestimation. Strictly speaking, the maximum PNdB should be determined from the series of PNdB for each moment, such as

TABLE 1. PNL-dB(D)-dB(A), tone correction, and duration for take-offs

Type	1/3 Oct. max. PNL (1)	Oct. max. PNL (2)	Oct. PNLM PNL (3)	dB(D), (K)	dB(A), (K′)	Tone correction (freq.)	Duration
						C(Hz)	t_2-t_1 sec.
DC-8-61	110	110	107.5	101(6.5)	96(11.5)	0.5(400Hz)	33
,,	109	109	108	101(7)	96(12)	0.7(400)	24
,,		105.5	104.5	98(6.5)	94(10.5)		26
B-720	112	112	110	103(7)	100(10)	0.5(500)	10
,,		111	109.5	103(6.5)	100(9.5)		30
SE-210	104.5	104.5	103	96(7)	93(10)	0.5(200)	35
,,		107	105.5	99(6.5)	96(9.5)		11
CV-880	113	112.5	—	105	103	0	13
,,	113	112.5	111.5	105(6.5)	103(8.5)	0	17
,,	114	112.5	112	106(6)	103(9)	0.5(160)	11
,,		110	108.5	102(6.5)	99(9.5)		20
B-727	114.5	113.5	112	105(7)	100(12)	0	10
,,	111	110.5	—	102	98	0.5(100)	14
,,	112	111.5	—	103	99	1	11
,,	105	104	103	97(6)	93(10)	1	18
,,	108.5	108	107.5	99(8.5)	95(12.5)	0.5(400)	12
,,	112.5	112	111.5	103(8.5)	98(13.5)	1	12
B-737	107	106	105	97(8)	93(12)	1	19
,,	110	109	—	100	95	0	16
YS-11	101.5	99	98	91(7)	84(14)	1 (160)	8
,,	100	99	98	92(6)	84(14)	1.5(160)	10
,,	98	98	96.5	89(7.5)	82(14.5)	0.5(250)	12
FS-27	96.5	96.5	95.5	88(7.5)	80(15.5)	2 (100)	8
,,	95.0	94.5	94.5	88(6.5)	80(14.5)	1 (160)	9
,,	96.5	95.5	95.0	88(7)	81(14)		8

half second intervals. Table 1 shows PNdB (1) calculated from the maxima of the 1/3 octave band pressure levels, PNdB (2) calculated from the maxima of the octave band pressure levels, and PNdB (3), the maximum PNdB obtained from the octave band analysis for every other second.

The results of the PNdB calculated from each method are, as expected, PNdB (1)>PNdB (2)>PNdB (3), and the difference is 1–2.5 dB. Accordingly, in order to obtain maximum PNdB of the aircraft flyover, the third method must be used.

Table 2 is the results for approaches. The PNLM in the table is the maximum of PNdB calculated at 1/2 second intervals by computor. The differences between PNdB thus obtained and dB(D) or dB(A), for take-off or landing noise, are summarized in Table 3, where dB(D) and dB(A) were measured through weighting networks, and it can be seen from these results that for the direct reading of PNdB, dB(D) would be appropriate.

(2) Duration

The duration correction should in principle, be calculated from the time pattern of PNLT (tone corrected PNdB), but its approximate value can be obtained from the recording of dB(D) or dB(A).

As the duration of the aircraft noise, the time length of 10 dB below the maxi-

TABLE 2. PNL-dB(D)-dB(A), and tone correction for approaches

Type	PNdB(1)	PNLM	dB(D), K	dB(A), K′	C
DC-8-61	114.0	113.4	107.5(5.9)	99 (14.4)	3.7(2500Hz)
CV-880	107	106.7	101.7(5)	96.5(10.2)	0
CV-880	105.5	105	99.2(5.8)	90.8(14.2)	3.4
CV-880	108.0	107.1	101.8(5.3)	97.5(9.6)	0.7
B-727	106.5	105.9	99.1(6.8)	92 (13.9)	1.3(3150Hz)
B-727	97.5	96.2	90 (6.2)	84.2(12)	0
B-727	98.0	96.3	91.3(5.0)	86.5(9.8)	1.5

C: Tone correction at PNLM.

TABLE 3. Average values of correction K, K′

	K(PNLM-dB(D))	K′(PNLM-dB(A))
DC-8	6.67	11.33
B-720	6.75	9.75
SE-210	6.75	9.75
CV-880	6.33	9.0
B-727	7.5	11.4
B-737	7	12
YS-11	6.75	14.75
FS-27	7.0	14.6

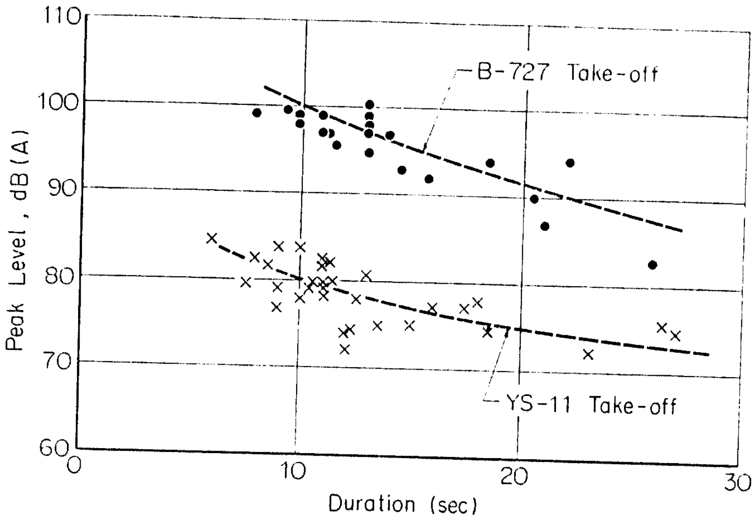


FIG. 2. Duration-dB(A) (Kushiro monitoring point).

mum value, (t_2-t_1), was obtained, and averaged for each type of aircraft. Then the duration correction can be approximated using $10\,log_{10}\frac{(t_2-t_1)}{20}$ relation. On the other hand, duration is related to the slant distance between the aircraft and the survey point, and if the power of noise emitted from one type of aircraft is constant, the duration ought to be related to the maximum noise level, and it can be estimated approximately from the slant distance and the velocity of aircraft (Appendix A). Figure 2 shows the relationship between the duration and the maximum of dB(A) obtained from the records at Kushiro monitoring point.*

The mean value of EPNL should be obtained by adding the duration correction to PNLTM (maximum PNLT) for each aircraft and then calculating the average, but for convenience, the average of duration correction can be added to the average of PNLTM, and there generally is little error to this method (Appendix B).

(3) Tone correction

To obtain the tone correction, approach or take-off noise was analyzed, and the correction value C was calculated according to the method established by ISO and ICAO. Table 4 is one example, the values of C at each sampling time are not always constant, and the *C* for PNLM (maximum PNdB) is not always maximum of *C*. On take-offs, *C* for jet aircraft is in the range of 0–1.0 (see Table 1) but for turboprop aircraft, the value is often 1–2.

(4) Calculation of TNEL (total noise exposure level) and ECPNL

The average of $EPNL_{ij}$ can be written as

$\overline{EPNL}_{ij}=\overline{PNL}_{ij}+\bar{\Delta}_{ij}+C_{ij}$ (see Appendix B)

$\bar{\Delta}_{ij}$: average of duration correction

$\overline{PNL}_{ij}$: average of PNL_{ij}

C_{ij}: correction for special irregularities

i: survey point

* Take-off noise is usually monitored at Kushiro, 4.5 km from the start of A-runway.

TABLE 4. Example of correction for special irregularities

SAMPLING NO. (0.5 sec. interval)	PNL(dB)	C	PNLT(dB)
1	69.5	0.0	69.5
2	82.7	0.0	82.7
3	83.3	0.5	83.8
4	72.2	0.0	72.2
5	67.7	0.0	67.7
6	86.0	0.0	86.0
7	88.9	0.0	88.9
8	89.6	1.0	90.6
9	93.5	1.0	94.5
10	95.9	1.2	97.0
11	90.5	0.5	91.0
12	97.2	1.2	98.4
13	94.6	0.5	95.1
14	97.2	1.0	98.2
15	100.4	1.1	101.5
16	101.6	1.1	102.7
17	104.4	1.5	105.9
18	105.7	2.0	107.7
19	106.9	1.5	108.4
20	108.3	2.3	110.6
21	110.0	3.0	113.0
22	108.5	2.7	111.2
23	110.7	3.2	113.9
24	112.3	3.5	115.8
25	110.8	2.3	113.2
26	111.2	2.2	113.4
27	110.6	2.8	113.4
28	113.4	3.7*	117.1
29	112.1	3.8	115.9
30	111.0	3.7	114.7
31	106.6	3.0	109.6
32	104.5	3.2	107.7
33	103.1	3.5	106.6
34	101.5	2.4	103.9
35	102.6	2.9	105.5
36	100.7	0.8	101.5
37	94.5	0.5	95.0
38	93.2	0.0	93.2
39	91.3	0.8	92.1
40	89.8	0.5	90.3
41	85.7	0.0	85.7
42	82.4	0.0	82.4
43	77.7	0.0	77.7
44	72.3	0.0	72.3
45	75.1	0.0	75.1
46	75.1	0.6	75.7
47	73.1	0.0	73.1
48	62.4	0.0	62.4

j: category (aircraft type, destination, route, runway utilization)

When N_{ij} is the number of aircrafts of category j at point i,

$TNEL_{ij} = \overline{EPNL}_{ij} + 10 \log_{10} N_{ij} + 10$

Then $ECPNL_i$ for the period of one day (86400 seconds)

$$\mathrm{ECPNL}_i = 10 \log_{10} \sum_j \text{anti log}\left(\frac{\mathrm{TNEL}_{ij}}{10}\right) - 10 \log_{10} 86400$$
$$= 10 \log_{10} \sum_j \text{anti log}\left(\frac{\mathrm{TNEL}_{ij}}{10}\right) - 49.4$$

The determination of ECPNL was carried out as follows,

(a) The measurement was done in the range of 60dB(A)~110dB(A), and the maximum level of flyover below 60dB(A) was excluded.

(b) The maximum level, dB(A) was read from the records, the pen speed of the recording being 16dB/second. (according to ISO-R507)

(c) EPNL is the sum of dB(A), correction K′, duration correction Δ and the tone correction C. Regardless of the results of the preceding paragraphs, for the corrections of K' and C of jet aircraft, the values of the following Table were used refering to the suggestion of ICAO. (Table 5)

(d) The duration corrections were calculated provisionally for the maximum level above 80dB(A) with the equation $10log_{10}\frac{t_2-t_1}{20}$, for each type of aircraft, and added to PNLTM to obtain EPNL.

(e) ECPNL at each point was calculated according to the schedule in August. (Table 6)

(f) When number of aircraft observed was small at several locations, the correction for number of take-off or approach of a given type of aircraft at given day was considered as follows for simplicity,

TABLE 5. Corrections for land use purpose

		K′	C
Take-offs	Large and medium size jet aircraft	+13	0
	Turboprops	+14	1
Approaches	Large and medium size jet aircraft	+13	2
	Turboprops	+13	0

TABLE 6. Schedule of Osaka Int'l Airport in August, 1970

	Time	DC-8 -61	DC-8 -55	DC-8 -33	B-707	CV-880	B-727	B-737	B-720	YS-11	F-27
Dep.	0701–1900	4	4	1	5	2	44	20	3	71	19
	1901–2200	1	1	1	5	1	12	3		3	
	2201–0700						2			7	
Ar.	0701–1900	4	4	1	8	2	42	17	3	60	15
	1901–2200	2	1	1	1	1	12	5		15	4
	2201–0700		1				1			7	
		Total Dep. 25					83			10	
		Ar. 26					80			101	

N′/N	50%～80%	10 log N′/N	−2 dB
	30%～50%		−4
	20%～30%		−6
	10%～20%		−8
	below 10%		−10

N′: number of aircraft observed

N : number of aircraft scheduled

Survey of aircraft noise was carried out at 10 points per day and continued for 20 days. The data obtained at special weather conditions such as a rainy day and a windy day (more than 3 m/sec) were excluded.

IV. Method of Drawing the ECPNL Contour

Step 1 — The co-ordinate and values (ECPNL) for sampling points are given.

↓

Step 2 — Diagrams are divided into suitable numbers of rectangles and the value for each corner point is calculated.

↓

Setp 3 — Each rectangle is divided further into smaller rectangles and the values are calculated by interpolation.

↓

Setp 4 — Points for a given value (for example 80 ECPNL) are connected successively, and contour lines for each level are drawn.

The method of drawing the contour by computor is basically as follows:

The values of ECPNL are given to suitable positions on the map. Then the map is divided into several rectangles. The values of corner points of rectangles are calculated by using six data closest to the corner point, weighted so as to be the inverse of the square of the distance. The number of these corner points chosen was about 30×30 on a map of the area 15×15 km².

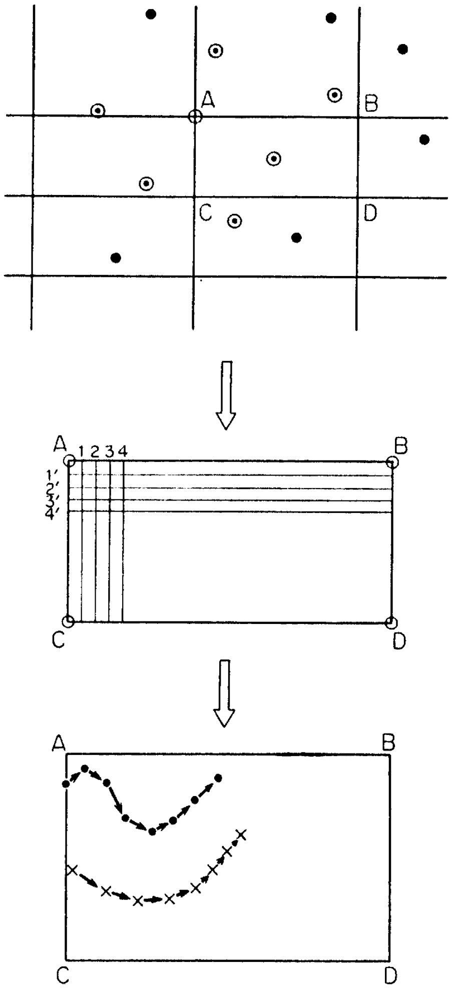
Further, these rectangles are divided into 10—100 smaller rectangles, and the values for the corner points of each are calculated from the four corner values of the larger rectangle by interpotation.

By moving the plotter on the map so that it will connect points of same values obtained out of 10,000–100,000 points, the contour shown in Figure 4 was drawn.

Details of the procedure is indicated in Figure 3.

V. Calculated ECPNL Contour for Osaka International Airport

On the other hand, the ECPNL contour for areas around Osaka International Airport can be drawn based on the data of FAA-No. 70-7. The calculations were made for nominal routes shown in Figure 5, with the DC-8-61 and B-727 as the typical aircraft. Noise exposure caused by turboprop aircraft can be neglected because of little effect to ECPNL. Further, for the flight profile of take-offs, category C of FAA-No. 70-7's Generalized Take-off Profiles was used, taking into



Step 1. Reference data are given to black points, and.

Step 2. Out of black points, ⊙ are used to obtain the value of point A.

Step 3. After calculating values of A, B, C, D, . . . by the above method, the rectangle is divided further into smaller ones, and then the values of crosspoints for each rectangles are calculated.

Step 4. The contour is delineated by connecting the same values out of data obtained by Step 3.

FIG. 3. Method of drawing ECPNL contour.

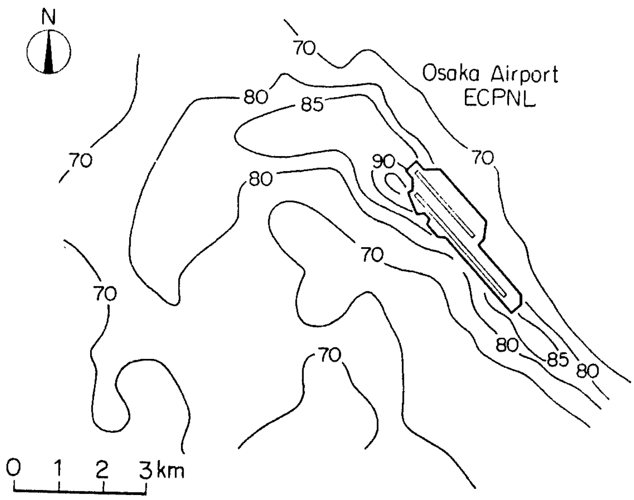
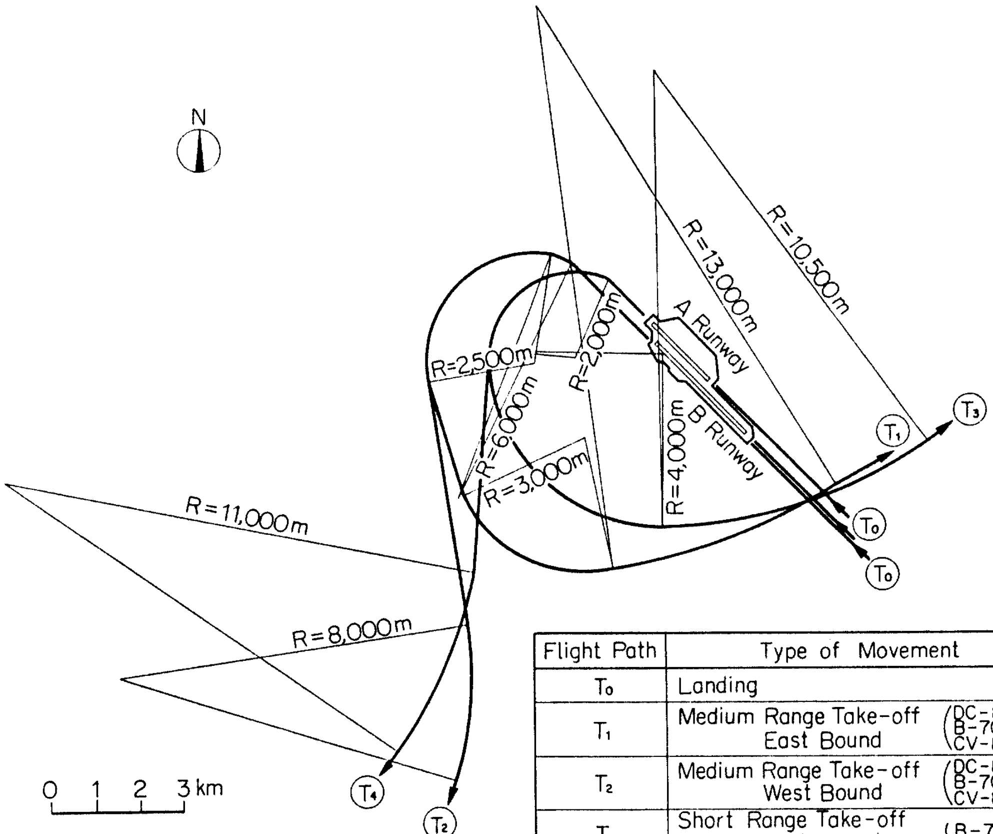


FIG. 4. ECPNL countour (measured).



Flight Path	Type of Movement
T_0	Landing
T_1	Medium Range Take-off East Bound (DC-8, B-707, CV-880)
T_2	Medium Range Take-off West Bound (DC-8, B-707, CV-880)
T_3	Short Range Take-off East Bound (B-727)
T_4	Short Range Take-off West Bound (B-727)

FIG. 5. Aircraft flight paths.

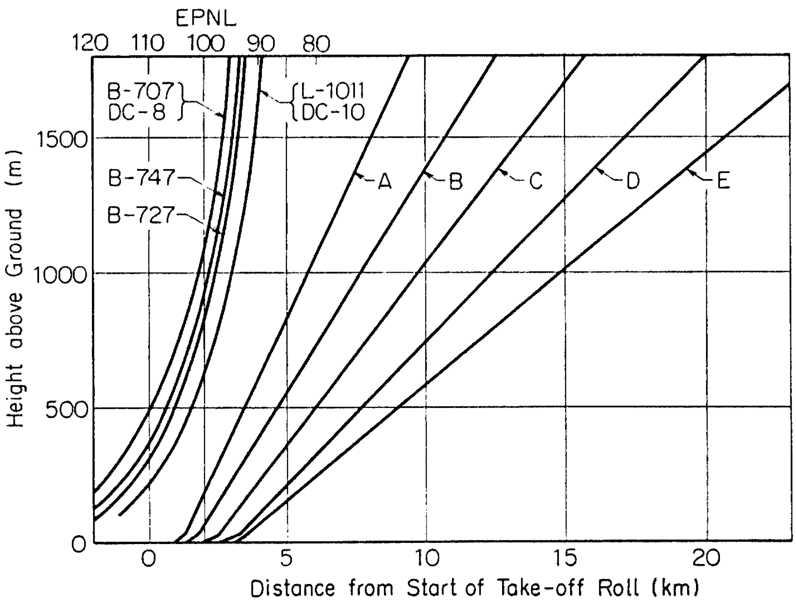


FIG. 6. EPNL-take-off profiles (from FAA No-70-7).

TABLE 7. Flight profile

Type of aircraft	Trip length in N. Miles						
	0–500	100—1,000	1,000—1,500	1,500—2,500	2,500—3,500	3,500—4,000	4,500+
B-707-320 DC-8-50.60	B	B	B	B	C	D	E
B-727-100	B	C	C	D	D		
B-727-200 B-737	B	C	D	D	D		
DC-9	B	B	B	B			
B-747	B	B	B	B	C	D	E
DC-10 L-1011	B	C	C	D	D		

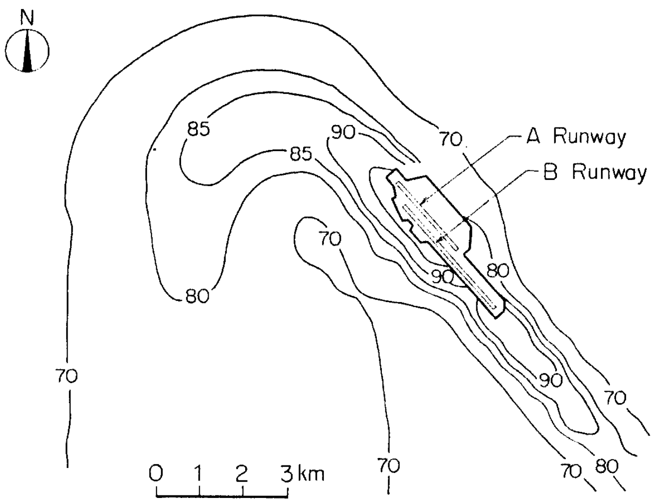


FIG. 7. ECPNL countour (calculated).

account the results of the flight height survey measured in areas around the airport. (Fig. 6 & Table 7).

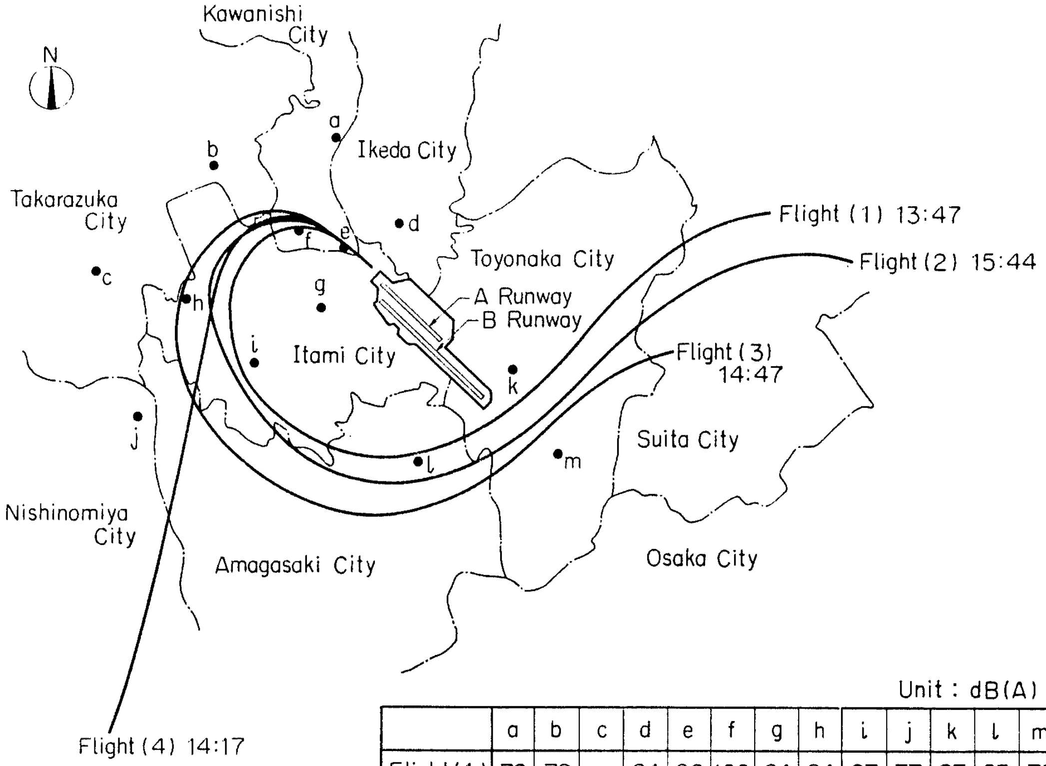
In this way, ECPNL contours shown in Figure 7 were drawn, without measurement.

Calculated contours show fairly good agreement with measured ones. Deviation between them is thought to be the variation of actual flight paths during measurements.

VI. FLIGHT PATHS ANALYSIS AND THE VARIATION OF THE NOISE LEVEL OBSERVED

The flight path of each aircraft at take-off was traced by radar. In Figure 8, the example of those of B-727 and the maximum noise level, dB(A), observed at several points are indicated. (Fig. 8)

The distribution of flight paths for B-727 are summarized in Figure 9, number



Unit : dB(A)

	a	b	c	d	e	f	g	h	i	j	k	l	m
Flight (1)	79	78	—	84	90	100	84	84	97	77	87	93	79
Flight (2)	79	85	—	82	91	98	85	89	87	77	83	89	83
Flight (3)	79	85	85	82	89	98	85	90	87	77	81	90	76
Flight (4)	81	85	70	90	99	99	87	90	87	87	—	65	—

FIG. 8. The vicinity of Osaka International Airport. (B-727 tako-off)

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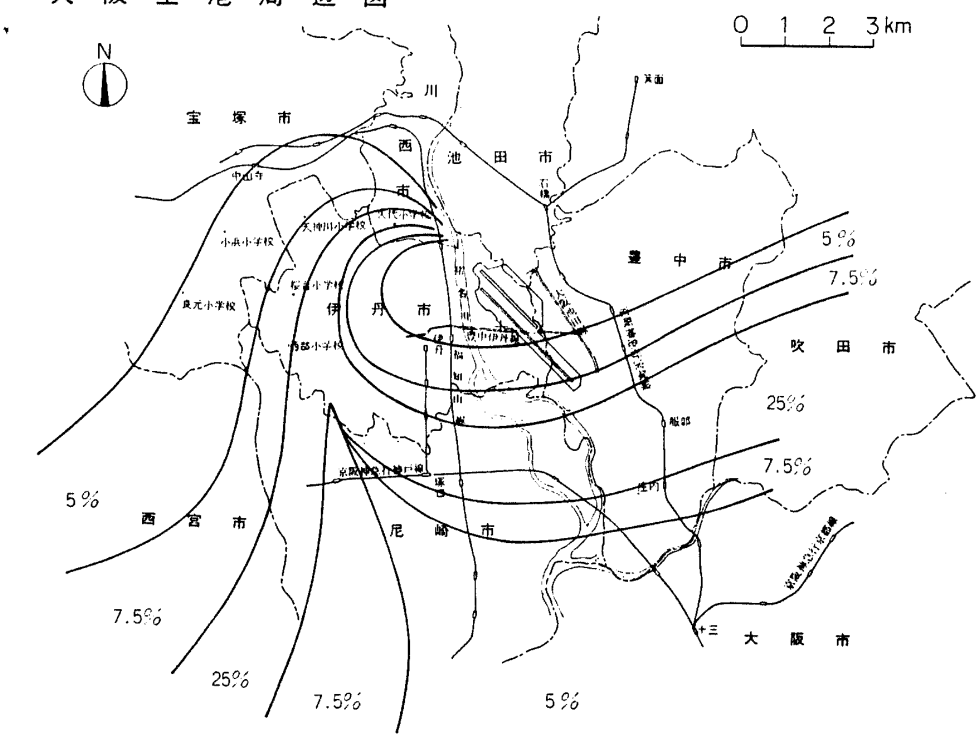

FIG. 9. Distribution of flight paths.

of aircraft observed is 171.

The height of aircraft at Kushiro monitoring point was measured by photograph too. The observed height for B-727 is as follows.

March 17 (mean head wind velocity, 6 m)
B-727 416 ± 76 m
March 18 (mean head wind velocity, 2.5 m)
B-727 325 ± 48 m

Kushiro monitoring point is 4.5 km from the start of A-runway.

The maximum noise level at specified point depends on the slant distance, accordingly flight path and height. The variation of the observed level at several points are listed below:

f.	Kushiro (take-off) (4.5 km)	B-727, B-737	91 ±4.4 dB(A)
h.	Sakuradai (take-off) (7 km)	B-727, B-737	84.4 ± 6.0
m.	Honan (landing) (2 km)	B-727, B-737	85.6 ± 2.5

Honan is located under the flight path of landing, 2 km from the runway threshold.

As expected from the operation procedure the variation of noise levels under landing approach is small compared with that of take-off.

VII. Land Use Program

The purpose of establishing the ECPNL contour was to draw up a land use program. The work of selecting appropriate ECPNL value dividing each zone is now under way simultaneously with the work of establishing ECPNL contour in future.

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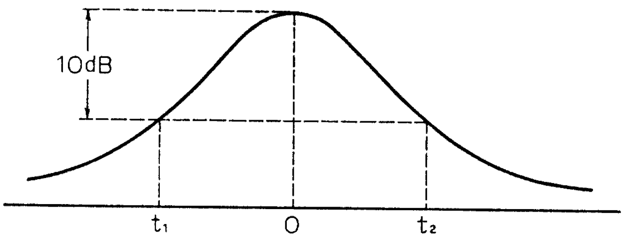
APPENDIX A

Duration allowance

For the sound source moving in a uniform velocity on the straight line, the noise level at the point of distance d can be expressed as,

$$L = \text{PWL} - 11 - 20\log_{10} d - 10\log_{10}\left\{1 + \left(\frac{Vt}{d}\right)^2\right\} \qquad (1)$$

where PWL: Power level of the sound source (weighted such as PNL or dB(A))
d: The nearest distance from the source to the observation point
V: Velocity of the source



The last term of (1) corresponds to the variation of the noise level, and (PWL$-11-20\log_{10} d$) equals to the maximum of the noise level.

Attennation by air absorption is neglected. In the figure, t_1 or t_2 is the time at which the noise level becomes 10 dB below the maximum value, then

$$10\log_{10}\left\{1 + \left(\frac{Vt_2}{d}\right)^2\right\} = 10$$

$$1 + \left(\frac{Vt_2}{d}\right)^2 = 10 \qquad \left(\frac{Vt_2}{d}\right)^2 = 9$$

$$\frac{Vt_2}{d} = 3 \qquad t_2 = \frac{3d}{V}$$

as the time pattern of the figure is symmetry

$$t_2 - t_1 = \frac{6d}{V}$$

if $V = 100$ m/sec & $d = 300$ m

$$t_2 - t_1 = 18 \text{ sec}$$

Approximate formula for EPNL is,

$$\text{EPNL} \doteqdot \text{L}_{max} + 10\log_{10}\left(\frac{t_2 - t_1}{20}\right) \qquad (2)$$

$$= \text{L}_{max} + 10\log_{10}\frac{1}{20}\cdot\frac{6d}{V}$$

$$=L_{max}+10\log_{10}\frac{d}{V}-5.2$$

$$=\text{PWL}-10\log_{10}d-10\log_{10}V-16.2$$

On the other hand EPNL is, from the definition

$$\text{EPNL}=10\log_{10}\left[\frac{1}{10}\int_{-\infty}^{\infty}\left[E_m\Big/\left\{1+\left(\frac{Vt}{d}\right)^2\right\}\right]dt\right]$$

then the duration allowance is

$$\varDelta=10\log_{10}\left[\frac{2}{10}\int_0^{\infty}\frac{1}{1+\left(\frac{Vt}{d}\right)^2}dt\right]=10\log_{10}\left[\frac{2}{10}\frac{d}{V}\tan^{-1}\left(\frac{V}{d}\right)t\right]_0^{\infty}$$

$$=10\log_{10}(\pi d/10V) \qquad (3)$$

where $10\log E_m=\text{PWL}-20\log d-11$.

From (3) if $V=100$ m/sec and $d=300$ m, calculated $\varDelta$ is -0.25 dB, and from the approximate formula, -0.45 dB.

For $V=100$ m/sec, $d=100$ m

$$\varDelta\ \text{cal}=-5.0\ \text{dB}$$

$$\varDelta\ \text{app}=-5.20\ \text{dB}$$

Appendix B

Error when the product of mean values is substitued for the mean of products.

Between the expectation $E(x)$, and $E(y)$ of variates x and y, and expectation $E(xy)$ of x, y, there is the following relationship.

$$E(xy)=E(x)\cdot E(y)+COV(x,y)$$

Here, $COV(x,y)$ is the covariance of x and y.

$$COV(x,y)=E\{(x-E(x))\ (y-E(y))\}$$

According to the difinition, the correlation coefficient η is, $\eta=\dfrac{COV(x,y)}{\{V(x)\cdot V(y)\}^{1/2}}$

$V(x)$ and $V(y)$ are the variance of x and y.

The error γ that results from substituting the product of mean values in place of the mean of products, expressed in dB, is,

$$\gamma=10\log_{10}E(x)+10\log_{10}E(y)-10\log_{10}E(xy)=10\log_{10}\frac{E(x)\cdot E(y)}{E(xy)}$$

$$=10\log_{10}\frac{E(x)\cdot E(y)}{E(x)\cdot E(y)+COV(x,y)}$$

using a general expression, it is,

$$\gamma = 10 \log_{10} \frac{m_x m_y}{m_x \cdot m_y + \eta \sigma_x \sigma_y} = 10 \log_{10} \frac{1}{1 + \eta \dfrac{\sigma_x}{m_x} \dfrac{\sigma_y}{m_y}}$$

The mean value is m_x, and m_y, and the standard deviation is σ_x, and σ_y. Accordingly, it can be realized that the error γ is dependent on the sharpness of distribution as well as the independency (η).

For example, in the case of large jet aircrafts approaching directly overhead at a certain point, with the mean peak value of noise of $m_x = 113$ unit*, the standard deviation, $\sigma_x = 107$ unit; and the mean value of duration $m_y = 11$ second, (10 dB below the peak), the standard deviation, $\sigma_y = 2.5$ second, the correlation coefficient η is -0.45, and the error γ when the product of mean values is substituted for the mean of products is,

$$\gamma = 10 \log_{10} \frac{1}{1 - 0.45 \times \dfrac{107}{113} \times \dfrac{2.5}{11}} = 10 \log_{10} \frac{1}{1 - 0.097} = 0.4 \text{ dB}$$

* Normalized value, reference level 74 PN dB.