Analysis of Aircraft Noise Sensitivity for Urban Airport: A Concept of Reference Noise Level

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Abstract: This study investigates individual noise sensitivity to change in aircraft noise levels for residents living near Fukuoka airport, which has proposed a capacity expansion plan. To better understand people' perception in aircraft noise, we introduced a reference point (RP) concept into analysis of noise sensitivity. A field survey consisting of social questionnaires and an innovative headphone interview system were carried out to assess general noise perceptions, annoyance & loudness sensitivities, and indoor noise levels. Different statistical analyses including structural equation model (SEM) and tobit regression were performed. It was found in SEM that there was a reduction in annoyance sensitivity due to an increase in perceived aircraft noise level. Further, results from tobit regression-based RP indicated that people are more sensitive to decrease in noise level than they are to increase one. Less sensitive to a larger aircraft noise implies an escalation in noise-accustomed levels.

Keywords: Aircraft noise, headphone interview, noise sensitivity, Prospect Theory, reference noise level

1. INTRODUCTION

Noise generating from landings and takeoffs at an airport remains critical. Nevertheless, airlines continue to schedule additional flights in order to meet the growing demand for air transportation services, while aviation authorities also aim to increase capacity through airport infrastructure improvements and airport (re)construction. Several efforts including noise mitigation programs, operational procedures have been proposed and improved to balance air traffic growth against both local and global environmental concerns (Girvin, 2009). The level of opposition to airport development plans by nearby communities and its potential to act as a constraint upon airport growth vary significantly with social and economic needs (Upham *et al.*, 2003). For example, airport-area communities that have less affluent populations are likely to be more tolerant of aircraft noise or feel unable to express their opposition. Such opposition would decrease further if local residents benefited from the continued growth of the airport (e.g., through employment, business improvement, easy accessibility). In addition, an appropriate response to a noise complaint needs to assure the individual that the complaint has been heeded and provided a satisfactory explanation. Otherwise, it can derail the planning consent process for new airport infrastructure or capacity increases.

In Japan, recent offshore airports such as Chūbu Centrair, Kobe, and Kitakyushu were constructed to meet the air transport demand and overcome the severe noise problem.

Furthermore, capacity expansion plan at Fukuoka airport has been under study by Fukuoka Airport Study Commission (FASC) since 2005. By considering the public opinions, FASC conducted a comprehensive study to assess the airport capacity, define a role of airport in Fukuoka metropolitan area, forecast the airport demand, provide countermeasures for increase in airport demand, and propose an optimal countermeasure for the airport to meet future demand (MLIT, 2012). FASC has proposed three alternatives, namely collaborations with nearby airport(s) (e.g., new Kitakyushu, Saga), additional runway(s) at existing airport, and construction of a new offshore airport. Note that Fukuoka airport is a rare case in Japan that aircrafts are flying at low altitude over the residential areas, the most populous city of Kyushu. Although people are exposed to high noise levels, there have been little complaints while many voices from residents agreeing to accept more flights (i.e., an additional runway at current airport) rather than transferring the airport into the sea. Unlike other airports, most of Fukuoka residents show noise acceptability rather than opposition.

Having seen the differences in noise perceptions, this study thus investigates individual noise sensitivity (i.e., annoyance and loudness sensitivities) to change in aircraft noise levels for Fukuoka airport-area residents. With efforts to better understand people's perception in aircraft noise, we present here an innovative concept of incorporating a reference-dependent approach into the analysis of noise sensitivity. The approach involves the use of reference point (RP) concept, based on which the noise sensitivity can be framed in term of gains and losses. A sound that one judges as noise may not be viewed as such in another; this reflects general sensitivity rather than something specific to sound itself. Even with the same level of exposure to aircraft sound, the degree of satisfaction among individuals varies. They may have set a specific threshold noise level (i.e., RP) and then react to noise exposure differently (i.e., they are generally satisfied (gains) with less aircraft noise and dissatisfied (losses) with more). Because the effects of aircraft noise vary, understanding individual differences in noise sensitivity is a crucial contribution to reducing complaints due to aircraft noise. It is also believed that an incorporation of RP into aircraft noise analysis may help understand individual differences in noise perceptions, specifically loudness sensitivity in terms of gains and losses.

In addition to earliest attempt of introducing the concept of RP into aircraft noise context, which is the main contribution of this study, we developed a headphone interview system to assess individual noise sensitivity and to investigate variations in individual sound thresholds. The system also allowed us to estimate actual indoor noise levels by using a playback adjustment protocol, and thus allowing us to analyze on aircraft noise sensitivity.

2. LITERATURE REVIEW

2.1 Aircraft Noise Sensitivity

The variation among individuals in response to effects of aircraft noise is often conceptualized as noise sensitivity (Smith, 2003). Some individuals are intensely annoyed at very low sound levels, while others remain calm even when exposed to higher noise levels. Such annoyance sensitivity involves a complex interaction of physical (i.e., noise level and frequency), biological (i.e., auditory system), psychological (i.e., signal interpretation and health status), and sociological processes (i.e., socio-economic status, culture, and lifestyle) (Schultz, 1978). It may further be affected by other factors including the fear of accidents, disturbance from other airport activities, and the level of public debate or opposition to airport development. To some extent, annoyance judgments can also be strongly influenced by non-acoustic variables (Green and Fidel, 1991).

Aircraft noise disturbance is a subjective issue related to the perception or tolerance of nuisance and actual noise level. Several previous noise sensitivity studies have focused on the relationship between aircraft noise metrics and the resultant adverse effects to sound levels including attitudes to noise, physiological sensitivity, health effects, behavior, and the proportion of highly annoyed participants (Berglund *et al.*, 1990). This technique is commonly based on correlation coefficients; high correlations are often understood as evidence that a close measure is also a measure of response.

In real-life situations, the nature of perceived annoyance is considerably more complicated than that of perceived loudness, defined as the subjective intensity of a sound independent of any meaning that the particular sound might have (Kuwano and Namba, 1996). There is evidence that perceived annoyance is judged differently from perceived loudness, although high correlation has been found between the two (Moreira and Bryan, 1972). Several researchers have also suggested that loudness is the dominant factor in producing annoyance (Berglund *et al.*, 1990). In this regard, a measurement of relative loudness may also represent a measure of annoyance sensitivity.

In most previous aircraft noise studies, noise level as a key indicator have been directly measured at targeted locations (e.g., Lim *et al.*, 2007), calculated based on aircraft noise modeling software like INM (e.g., Kamp *et al.*, 2004), and generated from noise contour maps (e.g., Kroesen *et al.*, 2008). However, these methods are costly and time consuming compared with the headphone interview method proposed herein. Although the in-home presentation of sounds to social survey respondents has been attempted in several large-scale studies, the headphone system may serve as one of supporting tools when estimating perceived noise levels and individual sensitivity to a variation of aircraft noise level.

2.2 RP

The RP is an important feature in Prospect Theory (PT) which was firstly introduced by Kahneman and Tversky (1979). RP serves as a baseline level that allows individuals to distinguish between gains and losses, and it has already been fruitfully applied in several contexts. Psychologists explain an RP as the decision-maker’s status quo, norm and social comparisons, an expectation, or an aspiration level. In gambling, the RP is a natural level that indicates whether players would win or not when bidding. In the fields of economics, marketing, behavioral finance, negotiation, purchasing, and stock investment, decision-makers seem to derive utility from certain reference monetary values including past, current, average, highest, and lowest prices (Baucells *et al.*, 2011). Additionally, an RP can also be defined by directly asking; for example, Arkes *et al.* (2010) and Baucells *et al.* (2011) utilized an emotion-based question to directly elicit the value of the RP in their studies. Specifically, subjects were asked to indicate a price level that made them feel neither happy nor unhappy.

In the past few decades, RP concept has attracted considerable attention from transport researchers. In transportation field, RP usually relates to time. Timmermans (2010) stated that “time serves as a proxy for the pleasure or need to conduct activities, including travel.” In a route choice context, RPs include free flow, habitual, expected, actual, and average travel times (Avineri, 2006; Gao *et al.*, 2010). In departure time choice settings, researchers have utilized multiple RPs; for example, Jou *et al.* (2008) assumed two RPs, namely the earliest permissible arrival time and the official work starting time. Similarly, Senbil and Kitamura (2004) additionally incorporated a preferred arrival time, while Schwanen and Ettema (2009) focused on the choice of whether to ask one’s partner to collect the child(ren) from nursery.

They introduced three RPs, namely the time that most other parents collect their child(ren), the time regulated by the nursery management that children should be picked up, and the closing time of the nursery. However, there is no known study incorporating RP in the context of examining aircraft noise.

An RP is not only context-dependent but also specific to an individual. In travel behavior analysis, Avineri and Bovy (2008) suggested three approaches to defining the RP value: (i) defining it based on mean/median travel time, (ii) directly asking for the RP value, and (iii) deriving parameter values from stated/revealed preferences. Progressively, recent researchers have focused on the dynamic properties of RPs (e.g., Avineri and Bovy, 2008; Arkes *et al.*, 2010; Baucells *et al.*, 2011), investigating how they are updated and formulated. However, no standardized methodology thus far exists for setting RP values (Avineri, 2006; Gao *et al.*, 2010; Timmermans, 2010).

2.3 RP vs Loudness Sensitivity

According to a survey of previous studies, most RP values are associated with money and time. However, specifically in an aircraft noise context, an RP is expected to be a noise value that represents the neutral sound level that distinguishes a feeling between a pleasurable one (gain) and an unpleasurable one (loss). In the early stage of this work, a range of aircraft noise levels was considered for the RP, including those experienced in the past, current noise exposure levels, average noise levels within residential areas, self-reported threshold sound levels, and changes in future noise levels following airport expansion. Even though current noise exposure levels seem to be the most appropriate values for the RP, there is no supporting evidence. Moreover, since we lack a sufficient model to measure the RP, a suitable RP value is chosen from the annoyance sensitivity analysis presented in this paper. It should be noted that the general term RP is hereafter replaced with reference noise level (RNL) to represent the neutral aircraft noise level for airport-area residents.

Though annoyance is a well-known indicator that has been used by many aircraft noise researchers, it is a complex experience involving multiple factors and is difficult to use as a main variable to estimate noise sensitivity function based on RNL. In this study, loudness responses was selected and used as main variable to investigate the behavior of noise sensitivity in gains and losses relative to RP, because it is simpler and may better represent annoyance. The annoyance response is then used to investigate the change in an individual RNL.

3. METHODOLOGY

The data used in this study was obtained from a field survey that consists of social questionnaire survey and headphone interview with residents living near Fukuoka airport from January 15^{th} to 24^{th}, 2011.

3.1 Social Questionnaire Survey

A total of 713 paper-based questionnaires were distributed to those residents who are living just below the flight paths and are exposing to low, moderate, and high noise-affected areas, as shown in Figure 1. All questionnaires were accompanied with each a stamped envelope, so that respondents were given enough time to complete the form prior sending back. The feedbacks were received at 379 (effective rate of 53 percent) while only 318 (178 females) were valid for the analysis after information screening process.

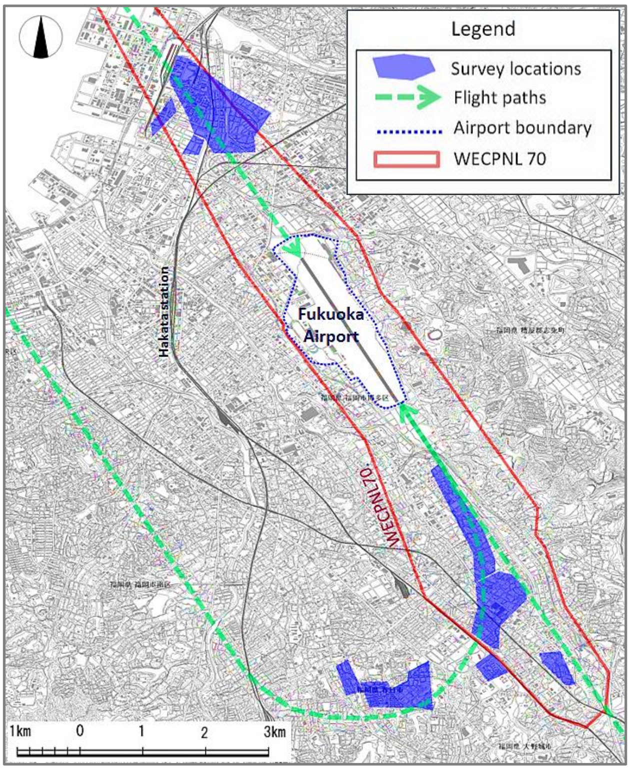

Figure 1. Survey sites at Fukuoka airport

The social questionnaire survey composed of four parts. Part I inquired about general awareness and control over aircraft noise. Part II inquired about consciousness against aircraft noise countermeasures provided by the government. Part III inquired about perspectives toward Fukuoka city and airport. And Part IV inquired about personal information. Most of the questions were designed using seven-point scale because it is easy for respondents to decide their judgments (Miller, 1956).

Table 1. Descriptive statistics for social survey data (*N* = 318)

Age (Years)	Percentage		Occupation	Percentage	Structure type	Percentage
	Male	Female				
20-29	2.1%	3.4%	Employee/Public officer	28.0%	Reinforced concrete	39.9%
30-39	11.4%	16.9%	Part-time job	8.5%	Wood	50.9%
40-49	16.4%	19.1%	Full-time housewife	31.1%	Steel beam	8.2%
50-59	21.4%	24.7%	Retired	20.1%	Others	0.9%
60-69	26.4%	23.6%	Others	12.3%		
70 or more	22.1%	12.4%				

Additional characteristics	Mean	S.D.
Number of the family members [1, 8]	3.20	1.41
Number of children aged below 7 years, 64 obs. [0, 3]	1.45	0.69
Number of automobile in the house [0, 4]	1.24	0.78
Number of hours/day of staying at home during weekdays [0, 20]	8.96	4.41
Number of hours/day of staying at home during holidays [4, 24]	11.51	3.21
Levels of the living floor of an apartment, 117 obs. [1, 13]	5.38	3.38
Number of living years at current house up to 2011 [1, 81]	25.24	20.03

Note: Values indicated in the square brackets imply [min, max]

The descriptive statistics of the participants and their dwellings are shown in Table 1. Most of the participants are over 30 years old. Approximately 50% of them have no job, 30% are full-time homemakers, and 20% are in retired status. A number of them are flight users and few possess a job at Fukuoka airport. Their houses are mainly made from wood and reinforced concrete structure. In average, there are three members in the family with more than one children whose age below seven. Usually, participants spend time at home from zero to 20 hours per day during weekdays and from four to 24 hours per day during holidays. Approximately 37% of participants are living in an apartment with the average living floor level of five, and with the highest of 13. They have resided at the current houses since 25 years ago in average, while about 13.5% of them have resided there since birth.

3.2 Headphone Interview

By the time of distributing the social questionnaires, two surveyors requested approximately 250 residents whether they would like to take part in the headphone interview. A total of 59 normal-hearing residents (effective rate of 23 percent) voluntarily participated, and only 50 (37 females) were valid for this study. Participants were solicited door-to-door by canvassing the residential areas shown in Figure1, and they were recruited without any monetary incentive.

3.2.1 Noise sources

Two single-flyover sounds from landings of B777-300 and CRJ-100/200 were recorded using a binaural microphone (Ronald R05) northwest of Narita International Airport's B runway, approximately 6 km from the runway center and at an altitude of approximately 300 m. Since we are focusing on the effect of single aircraft noise, in this study, the maximum sound level (L_{max}) measured in "Fast" time weighting was selected as the acoustic unit. Four recorded sound levels were initially considered for the headphone interview: L_{max} of 50.0 & 70.0 dBA from CRJ-100/200 with a duration of 30 s and 55.0 & 60.0 dBA from B777-300 with a duration of 40 s. Aircraft noise levels from 50.0 to 60.0 dBA are perceived to be quiet to comfortable, while 70.0 dBA is considerably noisy for humans (Branch and Beland, 1970). According to the playback volume and frequency settings (i.e., difficulty in calibrating the amplifier output voltages) of the reproduced sounds through the headphone system, however, the four levels used were 49.9, 55.5, 60.4, and 70.6 dBA, respectively. The first two sounds represent the actual recorded levels inside a car with widows closed, the third sound was obtained by increasing output level from L_{max} of 55.5 dBA, and the highest sound represents the actual recorded level inside the car with windows open.

3.2.2 Headphone system

The recorded sounds were reproduced by a playback system (Ronald R05) and presented to a participant through headphones (Sony MDR-ZX700). By using an airtightness dynamic system, the soft earpads of the MDR-ZX700 can effectively cover the gaps around the ears, thus providing a high degree of passive noise insulation. In addition, this system can better maintain the characteristics of aircraft sound compared with other systems such as earphones or (mini-) speakers. Compared with a laboratory experiment, the developed headphone system is easy to implement and inexpensive, and it can support the assessment of community responses to aircraft noises in the existing environment. However, the reproduced sound at low and high frequencies seem to be slightly "plugged up," contributing to the "dark" sound and making the bass sound a bit muddier than it should.

3.2.3 Procedure

The headphone interview consisted of three sessions. In Session 1, participants were asked about the quality of the recorded aircraft sounds, which were then evaluated on a five-point scale that ranged from "totally disagree" to "totally agree." Session 2 inquired about the perceived loudest aircraft sound level usually occurring at around 9 p.m. in a hypothetical situation in which participants were supposed to be relaxing or reading a book in a soundless indoor environment (no music or TV) with the windows closed. The recorded sound of the B777-300 was selected and presented to participants through the headphone system in accordance with the evening flight operation at Fukuoka airport. A volume adjustment method was used to assess the actual perceived L_{max} inside each dwelling. Playback-adjusted volumes were achieved based on a test/retest procedure in which each participant, under no time constraints, took an average of three to six times (approximately four minutes) to obtain the desired sound level.

Session 3 inquired about aircraft noise annoyance and loudness sensitivity. The L_{max} values of 49.9, 55.5, 60.4, and 70.6 dBA were presented consecutively with a few minutes break between. The hypothetical situation was the same as that described in Session 2 for the first three levels, while the windows were opened for the highest level. The aim of this "windows open" condition was to investigate aircraft noise sensitivity under different listening conditions. After hearing each sound level, participants answered two sub-questions. The first question asked how concerned they would be (annoyance sensitivity) if they heard the presented sounds at their homes based on a seven-point scale ("1" represents "not concerned," "4" represents "neither," and "7" represents "very concerned"). The second question required participants to compare the loudness level of each presented sound to the loudest aircraft sound they had reported in Session 2. Again, judgments were made based on a seven-point scale ("1" represents "very small," "4" represents "the same," and "7" represents "very large").

The interviews were conducted in quiet indoor environments and the background noise level was monitored using a sound level meter (RION NL-05A). This did not exceed 40.0 dBA, the lower limit of urban ambient sound. Because the indoor settings were different from one dwelling to another, a preparation of table with chairs or sofas was of primary interest and windows were closed during the interview period in order to increase the similarity of testing conditions. Each participant took approximately 40 to 45 minutes to complete all sessions.

3.2.4 Indoor L_{max}

Perceived indoor L_{max} were estimated using the playback-adjusted volumes from Session 2. Because it was unable to directly measure the signal level actually heard by participants, a pseudo ear made from artificial clay was created with a hole of 10 mm diameter to mimic the ear canal. In addition, a 35 mm long of 10 mm diameter plastic tube (to represent the ear canal) was designed and connected to the RION NL-05A's microphone (the tympanic membrane). The reproduced sound levels could then be measured by the L_{max} corresponding to each playback volume. The "adjusted volume" here refers to an amplifier output voltage that represents the sound level produced by the headphone system. The relationship between the adjusted volume (AV) and indoor L_{max} can be represented by a simple linear regression, $L_{max} = 0.62AV + 43.4$, with high R-square and t-test values.

3.2.5 Data summary

Summary of data obtained from the headphone interview shows that the average rating score of 4.36 based on a five-point scale in Session 1 indicates a high quality of the recorded sounds. The playback-adjusted volumes are in range from zero to 60 corresponding with indoor L_{max} values from 43.4 to 80.6 dBA, respectively. The average indoor L_{max} of the B777-300 occurring at around 9 p.m. is 56.9 dBA, and the average rating scores of both annoyance and loudness sensitivity increase with noise levels.

4. RESULTS OF SOCIAL SURVEY

Before giving details on analysis of aircraft noise sensitivity, we firstly conducted some basic statistical analyses on psychological data obtained from social survey in order to investigate general awareness to the current aircraft noise as well as consciousness toward Fukuoka and government.

4.1 General Noise Awareness

General aircraft noise awareness based on a seven-point scale is shown in Figure 2. While majority of participants stated that they held no fear of the flying aircraft, they would frequently imagine a crash or falling objects. Approximately 60% are concerned about the aircraft noise that interrupts their daily activities including normal conversations, speaking on telephone, and watching television. They become stressful if they hear aircraft noise during concentration. Though about 40% of them claimed that aircraft noise is source of daily nuisance, just minority claimed to suffer from nighttime sleep disturbance. Further, many participants are concerned about aircraft noise when both inside and outside their dwellings; even so, more than 60% claimed that they are now accustomed to it. As seen in Figure 3, though it appears that younger people are more accustomed to the current aircraft noise, results from one-way ANOVA shows no significant differences between noise-accustomed levels and age classes.

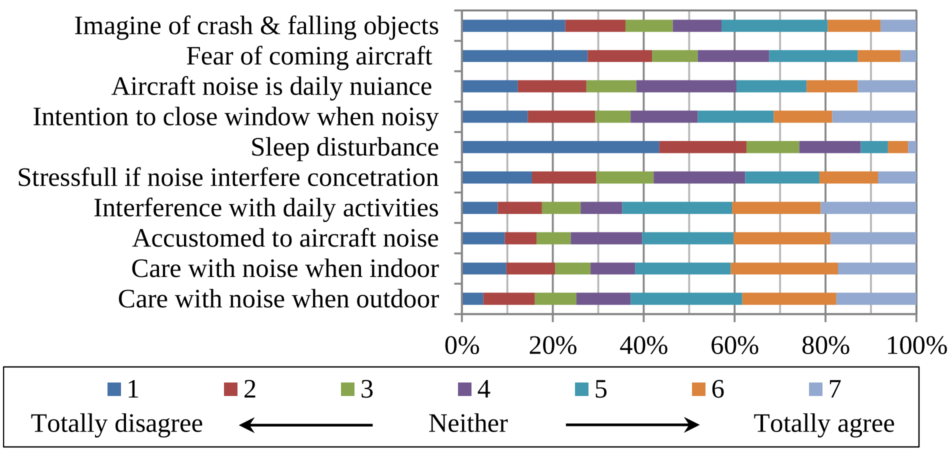

Figure 2. General awareness to the current aircraft noise (*N* = 318)

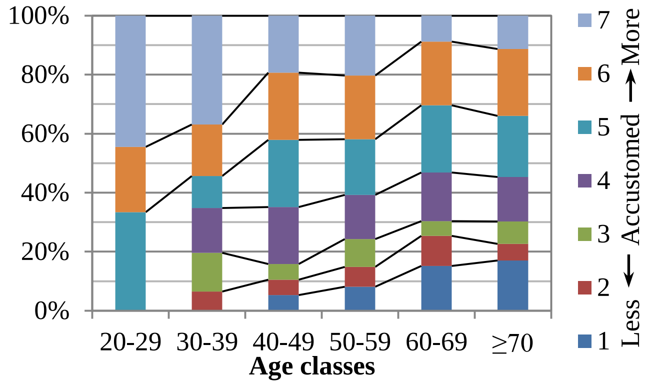

Figure 3. Noise-accustomed levels by age classes (N = 318)

4.2 Consciousness toward Fukuoka and Government

4.2.1 Toward Fukuoka city and airport

Figure 4 gives the general consciousness responses toward Fukuoka city and airport. Most of residents show strong satisfaction to the city of Fukuoka, and they (70%) are willing to contribute to the city development. More than 80% recognize the necessity of the airport existence and great benefits from its accessibility, yet less than 30% claimed about noise pollution and demanded for reduction in aircraft operations. The questionnaire also inquired about their opinions regarding the operation of a departure dispersion procedure with different flight route settings. The results showed that approximately 30% agree with the proposed operation and several gave a rating of "4," indicating their neutral opinion regarding future variation in aircraft noise.

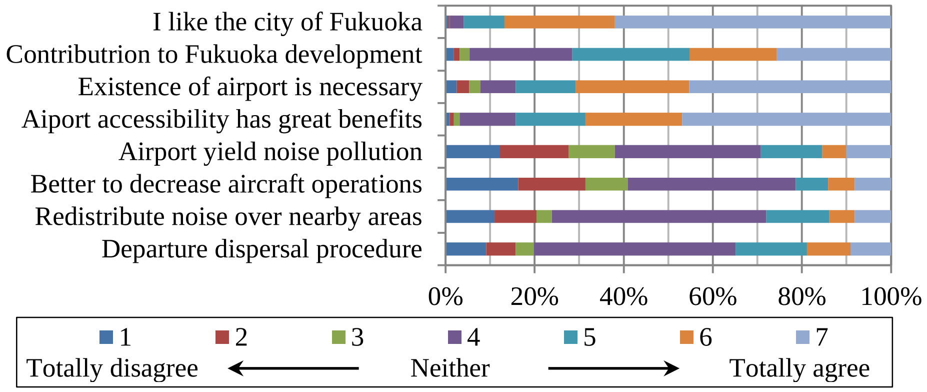

Figure 4. General consciousness toward Fukuoka city and airport (N = 318)

4.2.2 Toward government

The responses of consciousness to noise countermeasure provided by the government are plotted in Figure 5. As can be seen, the overall satisfaction level from residents to the government in dealing with the aircraft noise pollution around Fukuoka airport is relatively low. Many of them have rated on score "4," which indicate their neutral judgment on the current aircraft noise countermeasure provided by the government. Approximately 35% claimed that the government has ignored the noise pollution, has not provided enough noise support, and has not appropriately considered their opinion regarding the noise problem.

Therefore, more than half wanted the government to focus more on noise pollution near the airport.

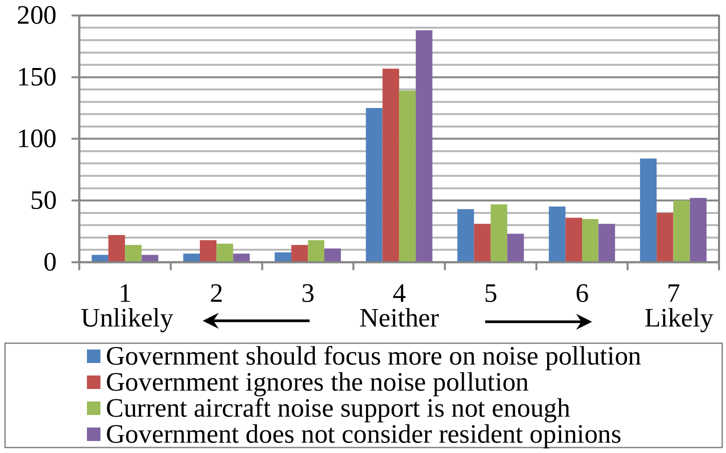

Figure 5. General consciousness toward the government (N = 318)

5. NOISE SENSITIVITY

This section begins with a computation of transmission loss of aircraft noise and then gives details on noise sensitivity analyses; that is, annoyance and loudness sensitivity.

5.1 Outdoor-Indoor Attenuation

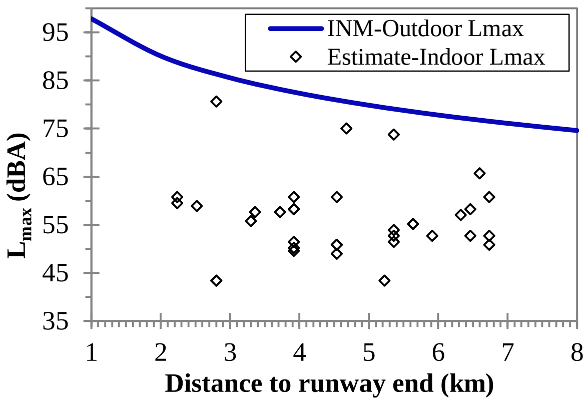

Figure 6. Variation of L_{max} against distance to runway end (N = 35)

The perceived indoor L_{max} of the 35 participants that live directly below the flight paths with an average distance of 4.63 km from their dwellings to the runway end, and their corresponding outdoor L_{max} estimated using INM 7.0 software for a single arrival of a B777-300 are illustrated in Figure 6. The perceived indoor L_{max} have no exact relationship with the outdoor L_{max} values or the distance to the runway end. In this particular case, it may not be appropriate to derive the value of indoor noise levels by using just a single value of transmission loss (e.g., Visser, 2005). Further, the magnitude differences between the indoor and outdoor L_{max} allowed us to compute an average transmission loss of 25.0 dBA. This outdoor-indoor attenuation is in the high range reported by U.S. EPA (1974). For preliminary

Japanese wood-framed and reinforced concrete dwellings near the airport, in particular, wall and window structures may be specially designed to insulate aircraft noise.

5.2 Annoyance Sensitivity

With assistance from the headphone interview system, we could obtain some data which are not usually available based on previous methods. The data, including perceived indoor L_{max} and individual noise sensitivity to the variation of aircraft noise, enable us to investigate the casual relations among interested variables under a construct of a structure equation model (SEM). The observed variables are presented by rectangles (shaded ones are data obtained from headphone interview), the unobservable (known as latent) variable is presented by ellipse, and direct effects from one variable to another are presented by an arrow. There are two features in SEM: one inspects for the effects on individual annoyance sensitivity, and another inspects for the effects of annoyance sensitivity and perceived indoor L_{max} on the annoyance feeling caused by indoor aircraft noise (i.e., latent variable). Note that we use data from both head headphone and social survey, and annoyance sensitivity was obtained by summing up the annoyance rating scores on each recorded sound. Thus, the available number of observations is 50.

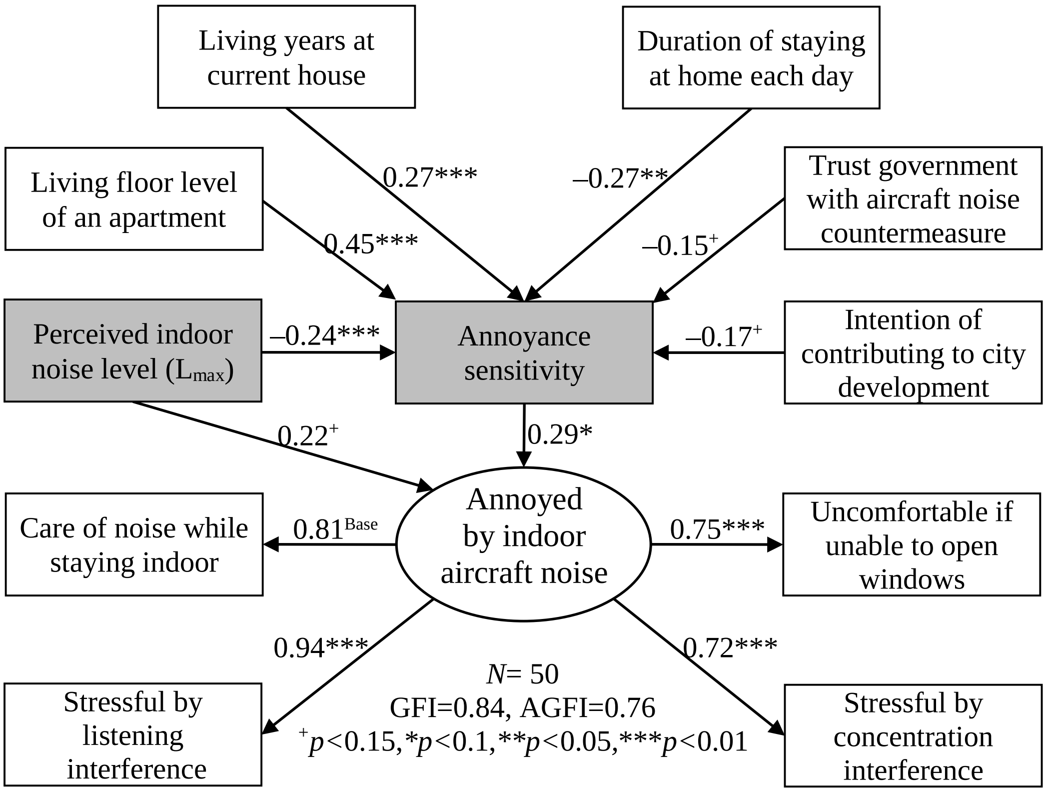

Figure 7. SEM structure and its estimate results

The SEM structure and its estimate results from SPSS AMOS 17.0 are shown in Figure 7. Proportion of the covariance observed in the data to the covariance explained by the model, that is the goodness of fit index (GFI), is satisfactorily good. For the annoyance sensitivity, results show that the number of living years (living floor level of an apartment) has positive coefficient, indicating that the longer the residing period (the higher the living floor level) the more sensitive to the aircraft noise would be. The positive effects reflect the situations that residents become more careful to an increase in aircraft noise in long term perspectives.

Further, the effects of home-staying duration, the average time during weekday and holiday, is found to be negative, implying that people's annoyance sensitivity decrease if they spend longer time at home. Similarly for the perceived indoor L_{max}, results suggest that there is reduction in annoyance sensitivity due to increase in aircraft noise levels. This implies that people are less sensitive to the higher aircraft noise, while they may gradually get accustomed to it. We also added two psychological variables (seven-point scale) to see its effects on annoyance sensitivity. Though both variables are not highly significant, probably due to the use of small sample size, results show that people's annoyance sensitivity would further decreases if they satisfy with noise countermeasure provided by the government, and if they have intention to contribute to the development of Fukuoka city and airport.

On the other hand, it is found that both annoyance sensitivity and perceived indoor L_{max} have positively significant effects on the annoyance feeling caused by indoor aircraft noise. This is obviously true in general. If one or both of perceived L_{max} and annoyance sensitivity increase(s), it adds the annoyance feeling against indoor aircraft noise levels. Even so, one interesting result is that the perceived indoor L_{max} itself reduces the degree of annoyance sensitivity. These relations can only be investigated when data on such annoyance sensitivity and perceived indoor L_{max}, referring to those variables in the shaded rectangles, are available.

5.3 Loudness Sensitivity

5.3.1 RNL from annoyance responses

The average rating scores and variation in annoyance sensitivity responses of the four recorded sounds are shown in Figure 8. The standard deviations indicate that participants' judgments on annoyance sensitivity for each sound level vary greatly. The average fitted curve shows that annoyance sensitivity seems to diminish for an L_{max} of 70.6 dBA, suggesting that participants might have reflected the condition that the window was assumed to be open. In principle, annoyance sensitivity should diminish if they had intended to keep the windows open. A one-way ANOVA test was performed, and the results indicated statistically significant differences between the average rating scores for each recorded sound ($F(3, 196) = 27.73$, $p < 0.001$).

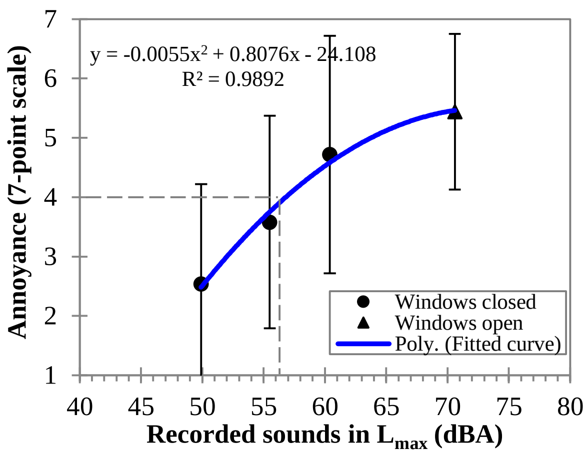

Figure 8. Average annoyance responses to recorded sounds (*N* = 50)

Further, a neutral line of annoyance sensitivity (a score of "4") falls between the average scores of 3.58 and 4.72, suggesting that people's noise thresholds range from 55.5 to 60.4 dBA. The range from 55.0 to 60.0 dBA can typically distinguish noise-sensitive from noise-insensitive people (Moreira and Bryan, 1972). The neutral line thus intersects the average fitted curve at an L_{max} of approximately 56.1 dBA. Since perceived annoyance has been found to be highly correlated with perceived loudness, the L_{max} obtained from this intersected point could be considered to be the RNL. However, there are no data for this L_{max}, and thus an L_{max} of 55.5 dBA (the closest value to 56.1 dBA) is assumed to be the population-based RNL for the loudness sensitivity analysis in this study

5.3.2 Loudness sensitivity-based RNL

The data on the relative loudness responses from the headphone interview enabled us to estimate the parameters that characterize the loudness sensitivity function for an RNL value of 55.5 dBA. We assumed that people are satisfied (dissatisfied) with their current exposure to aircraft noise in the gain (loss) region where their RNLs are larger (smaller) than the perceived indoor L_{max}.

Although the earpads were designed to fit the human ear and efforts were made to insulate passive noise, we noticed that some participants did not seem to put the headphones on properly during the interview. This may have led to uncertainty at high frequency sound levels due to minor shifts in headphone position, which might have resulted in inconsistent loudness evaluations. As seen in Figure 9, those inconsistent data that lie outside the gain and loss regions were treated as censored sample, and thus a tobit regression may be appropriate. Note that the original PT's value function is assumed to be S-shaped: concave in gains and convex in losses. In addition, it looms larger in losses than it does in gains because people tend to be more concerned about potential losses (i.e., loss aversion) than they are about potential gains. For this study, however, we selected linear tobit regression. The loudness function-based RNL proposed here is considered as a simplification and a representative of the PT's value function. Though PT incorporates the risky choice data to estimate the associated parameters, as an initial application of RNL in aircraft noise context, we use a simple seven-point scale data. To facilitate parameter estimation procedure the seven-point scale of 1–7 was later converted into a scale from −3 to +3. Estimations of tobit regression were performed for gain and loss regions separately. We relied on the maximum likelihood method to estimate the parameters for the following models:

$$V^{+} = \begin{cases} \alpha(\mathrm{RNL} - \mathrm{L_{max}}) & \text{if RNL} > \mathrm{L_{max}} \text{ and LHS} > 0 \\ 0 & \text{otherwise} \end{cases} \tag{1}$$

$$V^{-} = \begin{cases} \beta(\mathrm{RNL} - \mathrm{L_{max}}) & \text{if RNL} < \mathrm{L_{max}} \text{ and RHS} < 0 \\ 0 & \text{otherwise} \end{cases} \tag{2}$$

where

V^{+} and V^{-} : loudness rating scores corresponding with gains and losses,
α and β : parameters to be estimated, and
LHS and RHS : left- and right-hand side.

Table 2. Estimate results of tobit models for an RNL of 55.5 dBA

Region	Coef.	Value	*t*-stat	Observations		Log-Likelihood
				Uncensored	Censored	
Gain (N = 28)	α	0.2221	6.94	17	11	–33.7056
Loss (N = 22)	β	0.1241	4.87	17	5	–31.2008

The estimation results from STATA SE 8.2 are provided in Table 2. The results show that both coefficients are statistically significant, though it was not able to compute the pseudo *R*-square values for our models. For models with no intercept term, some researchers did not report nor interpret the meaning of *R*-squares. In practice, greater *R*-square for the model that passes through the origin does not mean this model is better (Tarasińska and Hanusz, 2008).

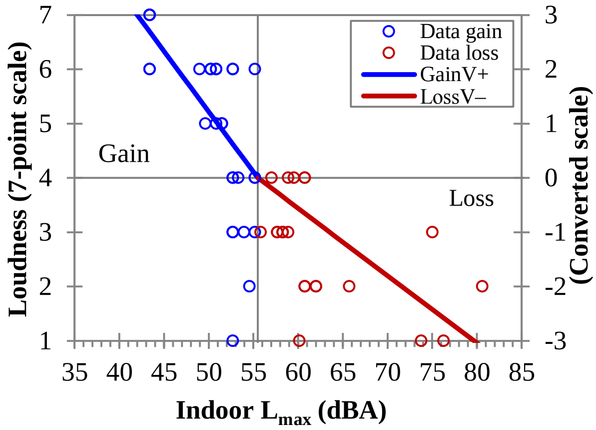

Figure 9. Loudness sensitivity responses and tobit regression results

The corresponding lines to the estimate coefficients α and β are illustrated in Figure 9. As can be seen, it looms slightly larger in the gain region than it does in the loss region, implying that people—compared with the RNL—are slightly more sensitive to a quieter aircraft noise level than they are to a louder one. The steeper slope in gain properties compared with in loss ones, for example, may be comparable with the similar property found in Senbil and Kitamura's (2004) work (see the estimated value function of departure time choice for their Decision Frame 2; Fig. 16 on page 30). Such steepness property (i.e., contradiction to the loss aversion property) found in this study may be resulted from the following three reasons. Firstly, major of airport-area residents have already accustomed to a large exposure to aircraft noise while expecting a higher satisfaction level if aircraft noise were to decrease, as can be inferred from the social survey responses. Secondly, results of being less sensitive to the increase in aircraft noise found in annoyance sensitivity and SEM sections may contribute to the steeper in gain region as well. Lastly, the assumption about the definition of the RNL value may also influence this property; that is, if indoor L_{max} values were defined as multiple individual RNLs, framing as gains would become losses and hence a different interpretation of the results may follow. We may argue that the steepness property of gains and losses in aircraft noise context may not necessarily be consistent to that found in other contexts, in which gains and losses that were judged based on monetary and time as outcomes. However, the property of being steeper in gains compared with in losses is opposite to what should be expected based on PT. With regard to noise sensitivity ratings, this finding implies that PT and the related concept of loss aversion do not seem to apply.

It should be noted that we also estimated the parameters for the original PT's value function (i.e., nonlinear form) and a simple linear regression using the available loudness data. Having compared the outcomes, tobit regression seems provide us a better loudness sensitivity function. Separate regressions were also performed to confirm the significant effects of the other variables on loudness sensitivity. The results indicated that, except for indoor L_{max}, the other variables, including personal attributes and dwelling characteristics, were not statistically significant. This result implies that only aircraft noise and RNL affect individual loudness sensitivity.

6. CONCLUSION

This study aimed at investigating individual noise sensitivity to change in aircraft noise levels for residents living near Fukuoka airport, where its capacity expansion plan is under consideration. Various statistical analyses were performed to better understand people's perception in aircraft noise. The basic statistical results showed that majority of residents acknowledge the benefits from existence of the airport. Though they are little satisfied with the noise countermeasure provided by the government, they indeed like the city of Fukuoka and will contribute to its development. Despite concerning on daily nuisance, many residents have already become accustomed to the aircraft noise.

Data obtained from the headphone interview allowed us to explore individual sensitivity to different aircraft noise levels. SEM results indicated that there is reduction in annoyance sensitivity to the increase in aircraft noise or longer period of time staying at home. This yields a primary conclusion that people may gradually get accustomed to the larger aircraft noise as long as they spend more hours at home. Furthermore, the analysis of loudness sensitivity using RNL concept allowed us to investigate different behaviors in gains and losses separately. It was found that individuals are more sensitive to a quieter aircraft noise level than they are to a louder one. Result of less sensitivity to the higher aircraft noise implies an increase in noise-accustomed level, which is consistent to that found in SEM and social survey responses. Although we initially confirm the applicability of RP concept in examining the effects of aircraft noise, defining multiple individual RNLs and incorporating an aircraft noise-associated risky choice would be of great interest for future studies in order to fulfill the theoretical background of PT.

We showed that noise sensitivity can be analyzed using different statistical methods, and corresponding results should be carefully interpreted. In particular, the idea of incorporating the RP concept into the analysis of aircraft noise effects is interesting and rather useful for aviation planners to study on community reactions to change in aircraft noise following airport capacity expansion plan.

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