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The characteristics and control strategies of aircraft noise in China

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Abstract

Aircraft noise pollution is a common challenge faced by the world. In China, this problem has drawn more and more attention from the local government and general public, as the average growth of aviation capacity exceeds 10% every year. Therefore this review paper aims to investigate the characteristics of China's aircraft noise, the underlying reasons for noise complaints, and the negative impacts of aircraft noise on human health. It is found that there is an increase, on average, of 3% hearing loss per exposure year in China. Aircraft noise can also bring potential damages to other physiological systems, such as the cardiovascular system. Along with the fast development of the aviation industry, complaints arising due to the disturbance of aircraft noise have occurred more frequently in China. For the residents living in the vicinity of the airport, aircraft noise can induce their annoyance at different levels, and it has been revealed that the areas and populations influenced by aircraft noise are predicted to grow steadily with the flight increase and airport expansion. Comparatively, Chinese residents might be more easily annoyed by aircraft noise. The differences among typical international aircraft noise standards and regulations, and the existing problems are also summarised. Finally this paper further explores the appropriate strategies for the reduction of aircraft noise, as well as the preventative legislation for the future.

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1. Introduction

It is predicted that the demand for international air transportation will annually increase by 4.5–5% in the next 20 years [1], whereas China's annual growth of both passengers and aeroplanes has already exceeded 10% in the past 5 years [2]. The rapid development of China's civil aviation industry not only promotes convenience and prosperity to the airport-located cities, but also causes a series of environmental problems, especially the noise pollution.

Aircraft noise pollution has several common features with other types of noise pollution, such as sensibility, locality, and temporality [3]. It also has some distinctive features, for instance, higher sound pressure level and wider sonic influence ranges in dozens of square kilometres [4]. A number of studies have indicated that people affected by long-term aircraft noise exposure are very likely to be impaired in hearing [5-10] and other physiological capacities [11-17]. In addition, their mental states, working efficiencies, and reaction abilities are negatively influenced to various degrees [18-27].

If aircraft noise pollution cannot be effectively controlled, it will lead to serious deterioration of important relationships between airports and surrounding residents, and the sustainable development of the aviation industry [3, 28-29]. From 2000, in being badly disturbed by aircraft noises, the relevant complaints and incidents occurred more frequently than before from the general public in China. Under this circumstance [30-36], the appropriate prevention and control of aircraft noise pollution have become extremely urgent.

Therefore, this paper aims to investigate the following questions: Firstly, what is the basic situation of China's aviation industry and airports? Secondly, in China, how does the aircraft noise affect human health? Thirdly, what are the actual measurements and predictions of airport noise in China? Lastly, based on the characteristics of China's aircraft noise, what kind of noise reduction and control strategies might be implemented? It is noted that, although a large number of cited reports and studies in this paper are written in Chinese, most of their abstracts are published in English.

2. Aviation Industry Development and Relevant Complaints

In recent years, China's aviation industry has boomed at a surprising speed [2]. As shown in Fig.1, more than 10% annual growth of airport capacity was achieved at China's airports from 2007 to 2012, in terms of the number of flight departures and arrivals and the number of overall passengers. The CAAC (Civil Aviation Administration of China) further estimates that approximately 6–7 new airports are built each year in China, there being 148 airports in 2007 and 180 in 2012, and most of the airports are expanded and refurbished every 5 to 10 years, by building new runways or terminal buildings [2]. For example, as planned in the 4th phase of expansion of Chongqing Jiangbei Airport, the 3rd runway will be constructed by no later than the end of 2015.

Table 1 summarises the basic information about China's main airports. It is noted that some airports were built much earlier than the listed year of operation. For example, the old Shanghai Hongqiao Airport was initially built in 1907 as a small military airport. The majority of the Chinese airports are connected to city centres via either light rail or metro, or this is under construction. At the moment, only Beijing Capital Airport and Shanghai Pudong Airport have 3 runways, and correspondingly, their runway operation modes are the most complex ones, in order to maximise the advantages of extra runways. An aircraft noise map is regulated as a compulsory document during the environmental assessment procedure in China, before the approval of any new airport or expansion projects. Moreover, a noise-monitoring device is claimed to be deployed at all the selected airports, but no such noise information can be found from the airports' websites. A notable noise problem is the large number of nocturnal departures and arrivals (11 p.m.–6 a.m.). For instance, there were 66 night flights at Beijing Capital Airport, as checked on a typical weekday. Compared to the relatively smaller airports, large airports often operate more night flights as expected, but there were few specific control strategies towards night flights at those airports. The only exception is Shanghai's two airports, carrying out the curfew restriction.

The Civil Aviation University of China [29] conducted a series of field surveys on the aircraft noise impacts of China's 121 airports in 1999 and its 148 airports in 2007, and the results are shown in Table 2. Their analysis indicated that with the fast development of the aviation industry, the aircraft noise pollution was rather significant, as the severely affected and relatively severely affected airports had accounted for nearly 15% in 1999, but this had risen by 4.1% from 1999 to 2007. However, the percentages of the slightly affected decreased from 70.2% to 62.8%.

More complaints have emerged recently from the local residents due to the excessive aircraft noise [30-36], as provided in Table 3. It can be seen that the major reasons for complaints about aircraft noise were often induced by the increased number of flights, low flight altitude, presence of night flights, and inappropriate flight routes. This is consistent with two surveys conducted at Zurich Airport in 2001 and 2003, suggesting a linear relationship between the noise exposure caused by the increase of flights and runways, and the annoyance level of surrounding residents [37]. However, China's main problem is the lack of a sound legal system on aircraft noise prevention and control, which leads to a large number of complaints and disputes that cannot be solved effectively [4].

3. Impact of Aircraft Noise on the Human Health

The physiological and psychological effects of aircraft noise have always been the concerns of the public. Like many other countries, China launched various social investigations and collected a great amount of research data, as presented in Table 4. Wu's research [5] indicated that 46.1% of overall ground crew members at 5 airports were severely impaired by aircraft noises in terms of their high-frequency hearings. In detail, 32.7% of crew members with less than 5 years exposure, 47.3% of 5–9 years exposure, 54.4% of 10–14 years exposure and 67.3% of 15–20 years exposure were identified as having impairment of hearing. Apparently, their impairment was aggravated with the increase of their working years. Similarly, Li's study [6] proved that for ground crew who had worked for less than 5 years, only 14.3% experienced noise-induced hearing loss, whereas it rose to 50.0% and 82.9% for people with 6–9 years and over a decade of service, respectively. Huang et al. [7] discovered that during their investigation of 32 ground crew members, there were 0% (having had less than 5 years exposure), 12% (5–9 years), and 20% (10–19 years) of the staff with noise-induced hearing loss. Alarmingly, all the 3 members who had worked for more than 20 years had serious noise-induced hearing impairment. In addition, Zhao's survey [8] on 154 ground crew members at two air force airports indicated that the severely impaired members with high-frequency hearing loss accounted for 51.9% in total. Similarly, Gao et al. [9] stated that in their research the hearing impairment tended to increase along with the length of aircraft noise exposure on 873 airport-operating personnel, and their percentages of hearing impairment were 40.0% (with less than 5 years exposure), 47.4% (5–9 years), 57.3% (10–15 years), 54.8% (15–19 years), and 81.0% (over 20 years). Therefore, it is suggested that the closer to the noise sources and the longer the exposure years, the worse the hearing impairment would be. This is also in agreement with a noise study in Korea [10], where the prevalence rate of high-frequency hearing loss in all employees was 41.9%, and the incidences of noise-induced hearing loss were the highest in the groups of maintenance workers (65.2%) and firemen (55.0%), who are continuously exposed to aircraft noise. This indicates that the damages for the hearing of airport employees working closer to the noise source were likely to be more serious, as anticipated.

From the investigation conducted by Liu et al. [11] on one primary school located near the airport's main runway, it was revealed that the outdoor noise level L_{WECPN} (weighted equivalent continuous perceived noise level) of the students' learning environment was 98dB, which is 28dB higher than the Chinese national standard [40]. And 27.7% of the male pupils suffered from emotional instability. Li [12] compared the impact of aircraft noise on the students of two secondary schools near Guangzhou Airport and the city centre. There were significant differences between the two groups of students in terms of their hearing threshold, diastolic blood pressure and pulse. Regarding the students near the airport, their average diastolic pressure and pulse were 0.3kPa higher and 6.84 per minute faster, respectively. Meanwhile their distraction and memory loss were 35.7% and 17.4% higher. The results of Zhuang's research [13] on 112 ground crew members were in accordance with the above findings. Although the duration of the aircraft noise is normally short, it could still cause hearing impairments to half of the crew, as a result of its notable intensity level. Besides, the abnormal ECG (electrocardiogram) rate of the experiment group was 4.1% higher than that of the control group. Dou et al. [14] randomly sampled 67 aircraft crew members in one airport, and found that apart from the 14.9% noise-induced hearing loss, a large number of staff members experienced autonomic dysfunction, based on crew's self-assessment. For example, tinnitus occurred in 52.2% of the overall crew members. Wang's research [15] indicated that aircraft noise may not only cause considerable impairment to the auditory system of aircraft-manufacturing workers, but may also bring damages to their cardiovascular system, providing 41.4% of workers with abnormal ECGs and 9.8% with abnormal blood pressure. Similarly, for the airports at other countries, Yankaskas [16] found that 80% of selected Japanese soldiers, who were long-termly exposed to aircraft noise, were likely to get chronic tinnitus. Meanwhile, Black [17] carried out surveys on the effect of Sydney Airport's noise on residents' health and life quality, and it was discovered that the incidence of chronic noise stress and high blood pressure of residents living within the noise exposure area was respectively 261% and 274% higher than that of others far from the airport. Fig.2 displays the relationship between percent hearing damage and aircraft noise exposure in China, based on the compilation of the above studies [5-9, 13-15]. A linear regression (R^2=0.60) fit to the data included in this figure shows an increase, on average, of 3% hearing loss per exposure year, due to the negative impact of aircraft noise.

The research on noise's subjective annoyance is of significant importance as well. Different groups may have different annoyance levels under the same noise level [18]. Finegold [19] revealed that aircraft noise at varying periods in the USA can influence people's annoyance response differently. For instance, 8 a.m. to 9 a.m. was the least annoying period, whereas 1 a.m. to 2 a.m. was the most annoying period. Jiao's research [20] demonstrated that aircraft staff exposed to more noise disturbances tended to be more annoyed. For example, the noise disturbance rate was 20.0% at the lowest level of noise annoyance, but to 63.8% at the highest level of noise annoyance, as shown in Fig.3. In other words, the annoyance level was highly related to the degree of disturbance. Babisch et al. [21] investigated the subjective annoyance of residents living near 6 major European airports, and the annoyance rate caused by aircraft noise was surprisingly higher than the level recommended by the European standard. Correspondingly, based on the subjective annoyance of nearby residents at Hangzhou Xiaoshan Airport, Liu and Di [22-23] developed a high-annoyance curve for the noise exposure response, which was higher than the American, Korean and European surveys [19, 24-27], as illustrated in Fig.4. This implies that, comparatively, Chinese residents might be more easily annoyed by aircraft noise.

By analysing the information provided in Table 4, it is shown that in China it is mainly the airport ground crew who are suffered from hearing impairment caused by aircraft noise. With regard to those residents living under the influence of aircraft noise, they are more likely to be affected by long-term disturbance, which might lead to a series of psychological problems and functional declines of the human body. It is evident that under the same noise level, people's annoyance aroused by aircraft noise at areas with low background noise is much higher than that of those at the areas with high background noise [21]. Most of China's residential areas near airports are away from the city centre and regional highways, with a relatively lower background noise. On the other hand, most of the residents build houses by themselves, without sufficient attention to the essential soundproofing of windows and doors [22, 38-39].

4. Noise Measurements and Predictions of China's Airports

As aircraft noise can bring severe damage to human health, the accurate detection and prediction becomes particularly important. Since 1988, China began to implement the Environment Standard for Aircraft Noise Around Airport (GB 9660-88), which is still in use today [40]. It adopted L_{WECPN} [41] as the evaluation indicator for aircraft noise. It is recommended that the noise level at special residential areas, and cultural and educational areas should be less than 70dB, whereas the level at other living areas should be no more than 75dB.

$$L_{WECPN} = \bar{L}_{EPN} + 10\lg[\sum_{i=1}^{n}(N_{1i} + 3N_{2i} + 10N_{3i})/n] - 39.4\text{dB} \quad (1)$$

where N_{1i}, N_{2i} and N_{3i} are, respectively: the number of daytime flights, evening flights, and overnight flights on the specific day i. $\bar{L}_{EPN}$ is the average level of effective perceived noise during the whole flying time within n days:

$$\bar{L}_{EPN} = 10\lg\left[\frac{1}{N}\left(\sum_{i=1}^{n}10^{L_{EPNi}/10}\right)\right]\text{dB} \quad (2)$$

where L_{EPNi} is the effective perceived noise level during the i^{th} flight, and N is the total number of flights within n days. Different from L_{dn} or L_{den}, which are calculated according to loudness, the quantity L_{EPN} applies noisiness and tone correction.

Table 5 presents the actual measured data of aircraft noise in China's airports. Through the measurement and analysis of the noise impact at Wuchang Nanhu Airport, Zhou and Feng [42] concluded that the influenced area above 80dBA (L_{dn}) was as large as 18 km^2, whereas above 70dBA (L_{dn}) the area was 30 km^2. According to the survey completed by Liu et al. [43] at Tianshui Airport in 1987, the excessive aircraft noise could not simply spread out, due to the complex terrain of Tianshui Airport in a narrow valley. Considering the noise's disturbance on humans and the development of local tourism, it was suggested that the existing airport should be further moved to other suburban districts in the future, if possible. Based on the noise measurement and environmental assessment of Shanghai Hongqiao Airport [44], it was found that the regional coverage of area with L_{WECPN} >75dB was 22.5km^2, including 15 villages and an approximate population of 35,000, while the area noisier than 70dB was 46km^2 with 29 villages and 60,000 people affected. In 1994, Wang et al. [45] forecasted the future level of aircraft noise around Sanming Shaxian Airport, and it was revealed that the excessive noise area and the influenced population of the airport's surrounding areas clearly increased with the expansion of aviation business, as expected. Zhao et al. [46] analysed the take-off and landing aircraft noises at Shenyang Taoxian International Airport, and L_{WECPN} was between 66dB and 83dB at the distance of 0.5–5km from the runway. They also advised that in the forthcoming airport expansion projects, the new runway would have to be built reasonably far away from the noise sensitive areas, such as schools and hospitals. From the environmental noise data collected for the old Guangzhou Airport in 1998, He et al. [47] discovered that as a result of the frequent aeroplane departures and arrivals, teaching activities at more than 10 primary and secondary schools, health care treatment, as well as residents' everyday life under the airline route were all affected to varied degrees, and approximately 400,000 residents were estimated to be within the areas noisier than L_{WECPN}=70dB. Fortunately, the noise-influenced population was expected to be decreased to 188,500 after the relocation and reconstruction of the airport. Through the noise evaluation of one military airport in Zhengzhou, Zheng and Wang [48] obtained that during the busy seasons of airlines, the affected population in the areas with L_{WECPN} >75dB was 643 persons more than the annual average level. Lin and Zhang [49] applied the latest aircraft noise prediction algorithm [50], and calculated that the aircraft noise emitted from Hefei Xinqiao Airport could influence up to 5343 local residents in 2020, using L_{WECPN}=70dB as the baseline. On the basis of the measured noise data of Shanghai Pudong Airport, Lei et al. [51] forecasted the environmental impact of the new runway, in terms of the noise-influenced area, and verified the feasibility of the evaluation report. In the same way, Han [52] predicted that the noise affected area (L_{WECPN} >70dB) would be largely increased from the current 21.25 km^2 to 62.7 km^2 in 2020, after the construction of the new 3rd runway of Chongqing Jiangbei Airport. Another field survey in Beijing Capital Airport [39] revealed that the influenced population within the aircraft areas between 75 and 85dB (L_{WECPN}) was more largely expanded than ever before, possibly owing to the significant number of immigrants from the surrounding rural area.

As demonstrated above, the area and population affected by aircraft noise at every airport are surprisingly notable and still increasing. Some airports in China are placed too closely to the schools, hospitals, and residential areas. Moreover, the flight routes of several airports are designed to cross right overhead those noise-sensitive areas. Particularly, regarding the cities with complex terrains, the sound waves usually lead to more reverberations and echoes, and consequently worse aircraft noise effects might be generated.

5. Control Strategies for Aircraft Noise in China

Although the reductions upon the noise influenced population might be achieved after the airport reconstruction, the affected areas and population at many other airports are actually increased due to the newly built runways and increased numbers of flights. It is therefore necessary to implement appropriate control strategies for the aircraft noise in China, based on the local airport conditions.

5.1 Noise Sources

It is suggested that airports purchase the noise detection equipment and release the relevant measured data in time. Visual communication systems of noise detections and feedbacks should be constructed along with the application of low noise engines and aircrafts. Restriction of the high noise aircrafts, which are designed without sufficient quietness, should be established as well [51]. Airports should adopt quiet aircraft operation programmes wherever practicable, such as the application of large gradient taking-off to increase the distance between aircrafts and the noise sensitive area on the ground [39]. However, currently there are few airports in China employing the quiet flying programme and a night-flight ban. In contrast, many airports in other countries, like London, Paris, Sydney, Seoul, and Singapore, all made strict restrictions on the operation time of runways, and only the delayed flights are allowed to use the runways during the curfew time [47]. For multi-runway airports, rational allocations of runway tasks are essential according to the local conditions. For instance, it is reasonable to lessen the aircrafts' taking-off and landing tasks for the specific runway close to residential areas.

5.2 Noise Propagation

In China, most of the areas surrounding airports are villages and suburbs, and the houses of the residents often lack adequate soundproofing, as mentioned above. This situation can be improved by the installation of soundproofing windows and sound-insulated walls [53]. In agreement with a study on residential buildings near Beijing Capital Airport [39], the overall sound insulation was improved by 10dBA after the soundproof treatment, and positive responses were obtained from the residents with respect to the impact of soundproofing. The ICAO (International Civil Aviation Organization) states that for the expansion of old airports or the construction of new ones, proper land-use planning is considered to be the most effective strategy to reduce the impact of aircraft noise on the local community [54]. However, many cities in China have inappropriately planned new residences in the highly noise-affected area, and this will undoubtedly give rise to rather critical problems. Taking Sakura Garden Community in Beijing for an example, it is only 2.7km away from Beijing Capital Airport, and numerous complaints were reported related to the unbearable impact of annoying aircraft noise.

5.3 Prevention Legislation on Aircraft Noise

China's prevention laws and guidelines on aircraft noise were established in the late 1980s. Although there are now relevant regulations on aircraft noise under different legislative, administrative and departmental levels [4], generally these are still not sophisticated enough and are difficult to implement effectively in practice, compared with the Western countries. The latest mandatory national standard, Environment Standard of Aircraft Noise Around Airport (GB9660-88) [40], has been implemented for more than two decades. Improvements can be made with the following issues considered:

1) At present, almost all the noise standards and evaluation indicators in China for the acoustic environment in cities, buildings, industrial plants and highways apply the equivalent sound level L_{eq} or A-weighted sound level L_A, but L_{WECPN}, the indicator for aircraft noise, cannot be simply converted to L_{eq} or L_A [29]. Hence there are clear practicable difficulties in coordinating the acoustic indicators between airport planning and urban planning. For instance, contour maps of aircraft noise cannot be directly used to aid urban planning and architecture design [37].

2) The evaluation classifications of aircraft noise levels are oversimplified. In total, there are only two classification levels for the noise-influenced areas, given 70dB as the maximum level for the special sensitive areas and 75dB for all the other areas. It may result in uncertain degrees of inaccuracy and incompleteness in terms of the aircraft noise evaluation. Furthermore, the measured noise data and noise complaints are not released on the airport websites. Some Chinese airports claim that their noise detection system has been positioned, but their monitoring data is still not published yet and is not accessible to the public.

3) The research conducted by the OECD (Organization for Economic Cooperation and Development) in some countries indicates that the establishment of an aircraft noise charging scheme helps to control the aircraft noise more productively [55]. Generally speaking, apart from recovering the costs of regulation and associated environmental monitoring and improvement, the charging scheme also has the dynamic stimulating effect to motivate people's interests and innovations in the aircraft noise control technology, and accelerates the process of technical revolution [56-58].

Indeed, *China's Environmental Noise Prevention and Control Law* has specified the charging standard for noise pollution [59], but the problem is that this standard has not been updated for more than 10 years, and thus cannot fulfil the present economic requirement. Moreover, its proper application in the control of aircraft noise needs the vital contributions from every relevant government department. The control of aircraft noise in China should employ the mixed strategies combining direct restrictions in conjunction with fair financial measures [60].

5.4 International Standards and Regulations

To protect the sound environment and minimise the impact of aircraft noise, many countries have established the environmental standards of aircraft noises around airports. Typical international aircraft noise standards and regulations are summarised in Table 6. Noise limits are always linked to the functions of surrounding lands, and special concerns have been raised for those sensitive buildings, like residential buildings, schools, and healthcare settings.

Compared with other types of environmental noises (such as industry, road, railway etc.), assessment of aircraft noise is the most diverse. A number of indicators for the assessment of aircraft noise were developed internationally, and there are considerable differences among those indicators [61-62]:

1) Different noise level indicators to represent the corresponding noise influence when a single

plane flies over the ground — There are four main indicators, including L_{EPN} (effective perceived noise level), $L_{PN\,max}$ (max perceived noise level), L_{Aeq} (equivalent A-weighted sound level) and L_{Amax} (max A-weighted sound level). The former two are based on noisiness, whereas the latter two are originated from loudness.

2) Different calculation upon the number of flights — Some standards use the busiest day to account the flight numbers, while others choose the annual average number or median number.

3) Different noise weighting systems for different time periods — such as night and daytime, and three periods for night, evening and daytime. Generally speaking, the more weighted periods, the more accurate to residents' perceptions, but more complex calculations are needed.

4) Different cumulative methods for multiple noise events.

5) Different correction factors, such as pure tone correction and duration correction.

Despite the above differences of evaluation indicators, there are many issues in common. For instance, generally three basic contents are taken into account when considering the impact of aircraft noise, including aircraft noise levels, numbers of flights, as well as people's subjective perceptions of aircraft noise at daytime and night-time. Moreover, all the indicators were derived from considerable surveys, and were based on residents' perceptions.

6. Conclusions

Through the detailed review on the characteristics of aircraft noise in China, it has been shown that the average growth of aviation capacity exceeds 10% every year, and there are too many night flights at some international airports, causing prolonged noise exposure time. A number of complaints and incidents have emerged due to the expansion of airports and the inappropriate planning of new residences near the highly noise-affected areas. Under the long-term influence of aircraft noise, there is an increase, on average, of 3% hearing loss per exposure year in China. The majority of the affected people tend to be annoyed easily, and their mental and psychological states are also influenced to certain extents after the long-time noise-exposure. Besides, both the aircraft noise affected areas and populations indicate steady growth. Comparatively, Chinese residents might be more easily annoyed by aircraft noise. However, few Chinese airports carry out quiet aircraft operation schemes, and there is a shortage of efficient communications between the airport and the surrounding residents. With regard to the relevant environmental standards, the aircraft noise indicator L_{WECPN} cannot be directly used for the overall acoustic evaluation within the urban scale, and the classification levels of aircraft noise are oversimplified. Clearly, in the future studies more efforts are needed to further develop the corresponding prevention legislation on aircraft noise, and improve the strategies to better protect airport staff and local residents from the negative impact of aircraft noise.

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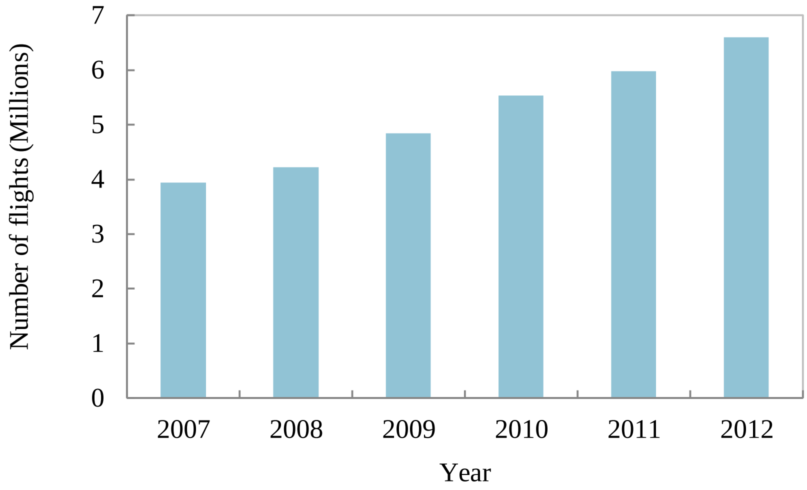
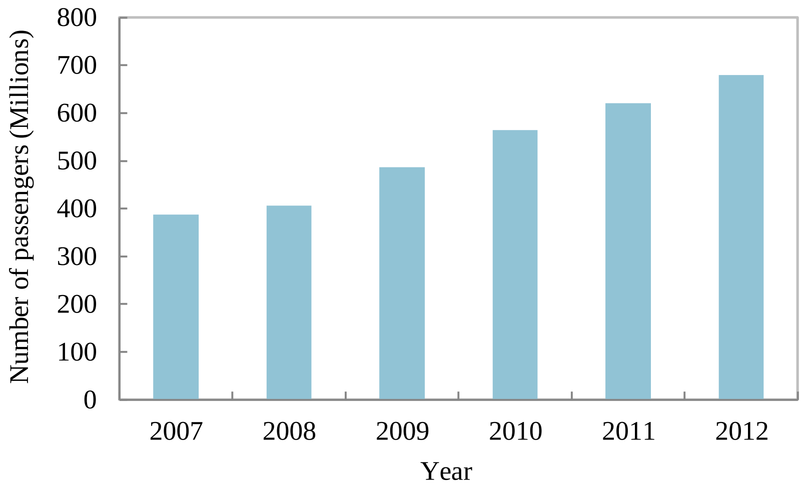


(a)



(b)

Fig.1 The increasing capacity at the Chinese airports from 2007 to 2012, (a) the number of flight departures and arrivals; (b) the number of passengers [2]

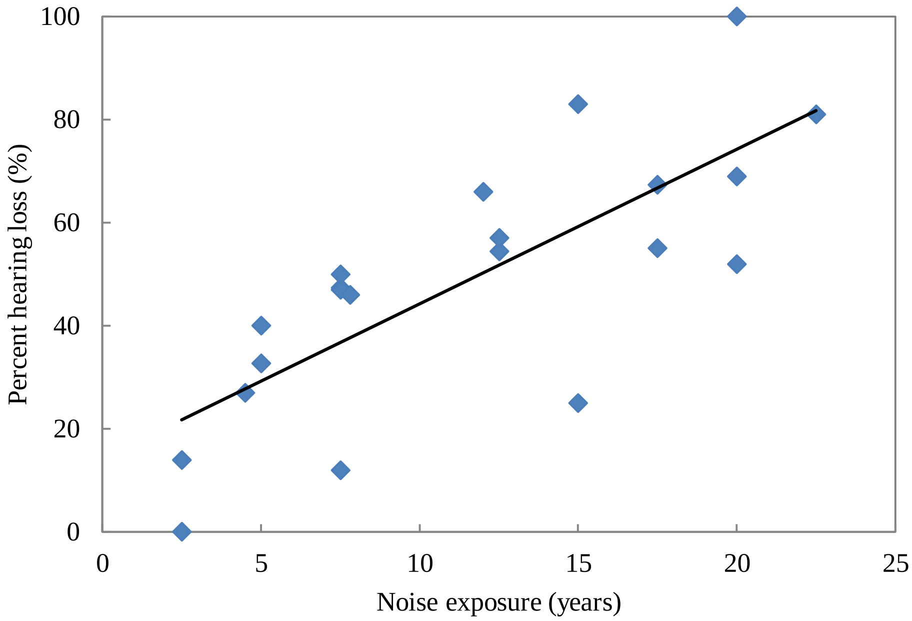


Fig.2 Relationship between aircraft noise exposure and percent hearing loss in China [5-9, 13-15]

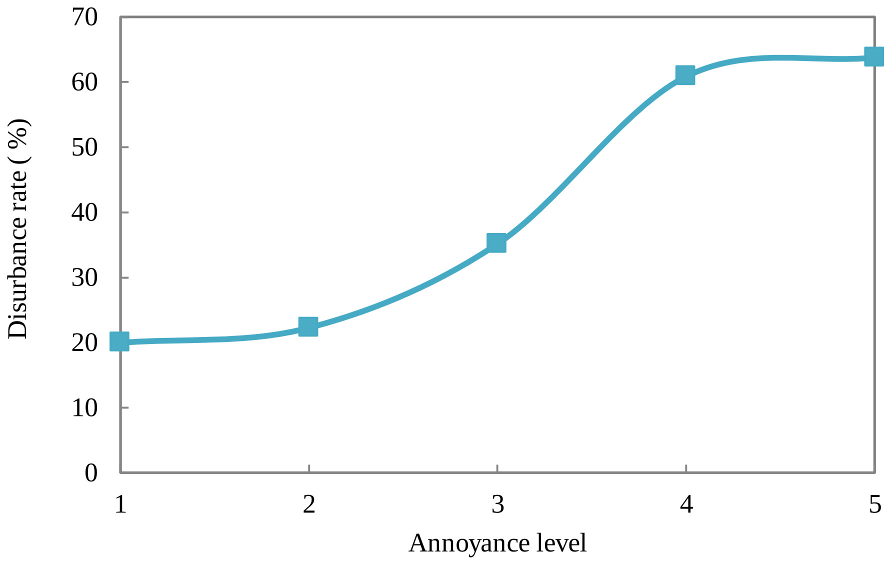


Fig.3 Relationship between aircraft noise disturbance and annoyance level at Chinese airports [20]

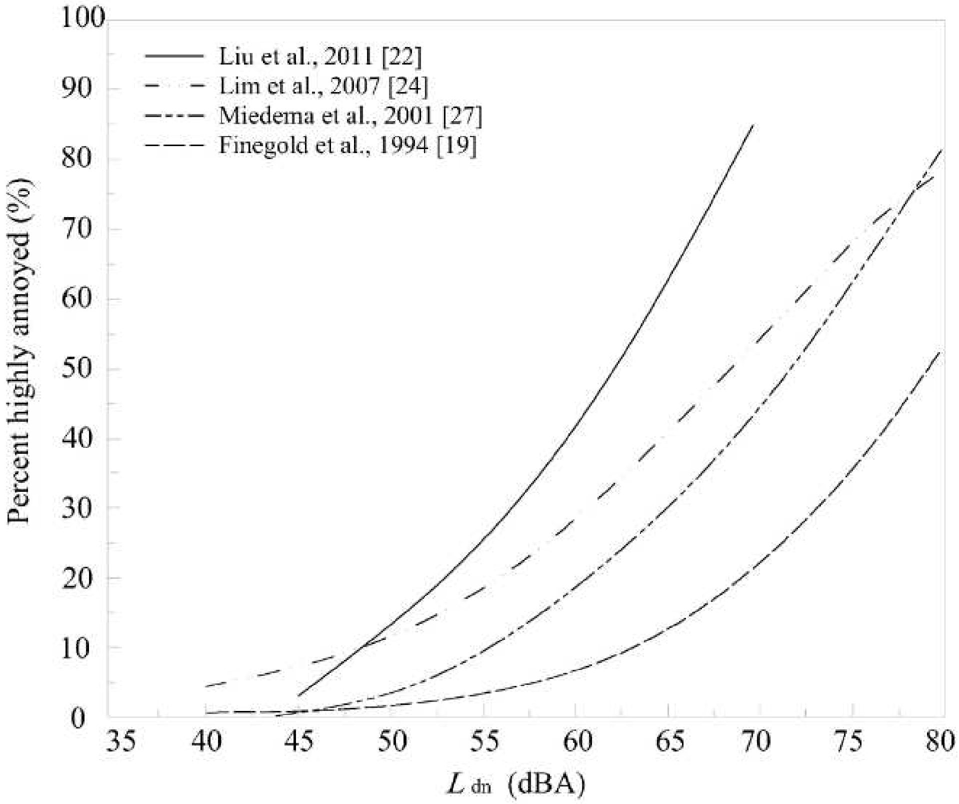


Fig.4 Relationship between aircraft noise level and percent highly annoyed at daytime in China, Korea, USA and European countries [19, 22, 24, 27]

Table 1 General information about China's main airports

Airport Name	Year of Operation	Airport Classification	Distance to the city centre	Metro/Light Rail connection to city centre	Number of runways	Runway operation mode	Noise map	Noise detection device	Noise information on the official website	Number of night flights (data accessed on 12th April, 2013)
Beijing Capital Airport	1980	4F	25km	Yes	3	Independent simultaneous parallel approaches, Dependent parallel approaches and Independent parallel departures (day time); semi-mixed/mixed operations (night time)	Yes	Yes	No	4 international departures, 55 domestic arrivals, 7 international arrivals
Shanghai Pudong Airport	1999	4F	30km	Yes	3	Independent simultaneous parallel approaches, Dependent parallel approaches and Independent parallel departures	Yes	Yes	No	Night flights prohibited
Shanghai Hongqiao Airport	1964	4E	13km	Yes	2	Segregated parallel approaches/departures	Yes	Yes	No	Night flights prohibited
Guangzhou Baiyun Airport	2004	4F	28km	Yes	2	Dependent parallel approaches and Independent parallel departures	Yes	Yes	No	11 domestic departures, 11 international departures, 63 domestic arrivals, 9 international arrivals
Chengdu Shuangliu Airport	1956	4F	16km	Under construction	2	Dependent parallel approaches and Independent parallel departures	Yes	Yes	No	2 international departures, 8 domestic arrival
Shenzhen Bao'an Airport	1991	4F	32km	Yes	2	Segregated parallel approaches/departures	Yes	Yes	No	International departure: 2 flights, 10 domestic arrivals
Chongqing Jiangbei Airport	1990	4F	21km	Yes	2	Segregated parallel approaches/departures	Yes	Yes	No	5 domestic departures, 3 international departures, 25 domestic arrivals, 1 international arrival
Hangzhou Xiaoshan Airport	2000	4F	27km	Under construction	2	Segregated parallel approaches/departures	Yes	Yes	No	4 domestic departures,37 domestic arrivals
Ningbo Leshe Airport	1990	4E	12km	No	1	Single runway independent operation	Yes	N/A	No	2 domestic departures, 1 domestic arrival

Note: According to ICAO's classification, Code 4E refers to L (the length of the runway) ≥1800m, 52m≤ WS (wingspan) <65m, 9m≤ T (the gap of two main landing tires) <14m;

Code 4F refers to L ≥1800m, 65m ≤WS <80m, 14m ≤ T <16m [60].

Table 2 Aircraft noise impact surveys in China [29]

Level of influence	**Features**	**Number of airports, 1999**	**Percent of the overall airports, 1999**	**Number of airports, 2007**	**Percent of the overall airports, 2007**
Severe	Airport has large flight capacity, fast growth, and several completed expansions. The local area is densely populated, and the residents strongly urge the relocation of the airport and compensation.	1	0.8%	4	2.7%
Relatively severe	Airport has relatively large flight capacity, relatively fast growth, and has been recently expanded or newly constructed. The surrounding residents actively approached the airport and local government to solve the noise problem. Some airport operations were interfered with before.	17	14.0%	24	16.2%
Average	Airport has average flight capacity, slow growth, and often is small or medium-sized with a long operating history. The surrounding residents have moderate responses towards the noise problem.	18	14.9%	27	18.2%
Slight	Airport has small flight volume. The surrounding residents make little or no responses and no further actions have been taken.	85	70.2%	93	62.8%
Total		**121**	**100%**	**148**	**100%**

Table 3 Recent complains due to aircraft noise in China

Date	**Location**	**Complain reason**	**Possible solution**
24th May 2006 [30]	Beijing Capital Airport	Unexpected change of flight routes without prior notice to the local residents	Better sound insulation in the residential buildings
26th March 2009 [31]	Guangzhou Baiyun Airport	Sleep disturbance	Residential relocation
27th October 2010 [32]	Shanghai Hongqiao Airport	New runway in use, increased number of flights, low altitude flight, many night flights	Redesign of runways, optimization of flying procedure, airport curfews, better sound insulation in the residential buildings
25th July 2011 [33]	Chengdu Shuangliu Airport	New runway in use, inappropriate flight route, many night flights	Optimization of flying procedure
1st July 2012 [34]	Hangzhou Xiaoshan Airport	Inefficient relocation plan in the local residential areas exposed with high noise levels	Under discussion
29th August 2012 [35]	Nanjing Lukou Airport	Sleep disturbance	Under discussion
24th September 2012 [36]	Shanghai Pudong Airport	New runways in use, increased number of flights, low altitude flight, disturbance on teaching activities, many night flights	Low noise aircraft, optimization of flying procedure, airport curfews

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Table 4 Impact of aircraft noise on human health

Author	**Method**	**Sample size**	**Gender ratio (male: female)**	**Age of subjects (average)**	**Noise exposure years (average)**	**Subjects**	**Noise level**	**Research environment**	**Physical impairment**	**Other health problems**
Li, 1990 [12]	Questionnaire+ listening test + environmental noise test + physiological measurement	Experiment group 89; control group 91	44:45	13-18	N/A	Students from a secondary school near Guangzhou Baiyun Airport, and another school in the city centre	L_{eq} 60.16-68.04dBA	Classroom + laboratory	Hearing threshold (11.6dB vs 8.54dB); diastolic blood pressure (9.4kPa vs 9.1kPa); pulse (76.98 vs 74.14 per minute)	76.40% distraction; 41.57% memory loss
Wu, 1990 [5]	Listening testing	Experiment group 410; control group 147	N/A	20-40	1-20	Ground crew at five military airports	L_{eq} 117-130dBA	Aircraft engine room + laboratory	Noise-induced hearing loss 6.1%; high-frequency hearing loss 46.1%	N/A
Li, 1996 [6]	Questionnaire+ Listening test+ physiological measurement	Group A 32; Group B 25; Group C 21; Group D 22	1:0	A:27.7 ± 5.0 B:27.0 ± 5.1 C:26.1 ± 5.5 D:24.6 ± 5.2	A:8.4 ± 4.7 B:7.4 ± 3.8 C:6.6 ± 3.8 D:5.4 ± 4.0	Ground crew at one military airport, A: machinery B:special equipment C: ordnance D: radio	N/A	Laboratory	Noise-induced hearing loss A:62% B:56% C:38% D:40%	N/A
Huang, 1998 [7]	Listening test	32	1:0	23-57 (33.75)	1-20 (9.6)	Ground crew at one airport	L_{eq} 80-90dBA	Terminal building + laboratory	High-frequency hearing loss 19.0%	N/A
Liu, 1999 [11]	Questionnaire	Experiment group 176; control group 179	47:41	9-12	N/A	Students from a primary school near airport, and another school far away from airport	L_{WECPN} 98dB	Outdoor	N/A	27.7% male students, emotional instability
Zhao, 1999 [8]	Listening test	154	1:0	N/A	7-33	Ground crew at two military airports	N/A	Laboratory	High-frequency hearing loss 51.9%	N/A
Zhuang, 1999 [13]	Listening test+ physiological measurement+ environmental noise test	Experiment group 112; control group 85	N/A	19-37(27.3); 20-36 (26.5)	1-20 (7.8)	Ground crew at Jinan's military airport	L_{WECPN} 99dB, maximum instant level 139dBA	Outdoor + laboratory	Noise-induced hearing loss 11.6%; high-frequency hearing loss 35.7%; abnormal ECG 41.1%	N/A

Dou, 2003 [14]	Questionnaire+ listening test	Experiment group 67; control group 67	N/A	20-37	2-7	Ground crew at one airport	N/A	Laboratory	Noise-induced hearing loss 14.9%	Vertigo 43.3%; tinnitus 52.24%
Wang, 2006 [15]	Listening test+ physiological measurement+ environmental noise test	Experiment group 703; control group 86	556:147	33.9	14.8	Aircraft manufacturing workers at Chengdu's Aircraft Manufacturer	L_{eq} 104-110dBA	Flight test factory + laboratory	Noise-induced hearing loss 56.9%; high-frequency hearing loss 73.5%; abnormal ECG 41.4%; abnormal blood pressure 9.8%	N/A
Gao, 2007 [9]	Questionnaire+ listening test	873	84:16	17-60 (29.8 ± 9.5)	1-40 (8.1 ± 7.6)	Ground crew at Beijing Capital Airport	N/A	Laboratory	High-frequency hearing loss 49.3%	N/A
Jiao, 2008 [20]	Questionnaire+ environmental noise test	Group A 100; Group B 96; Group C 98; Group D 96	N/A	20-40	N/A	Staff at four military airports (A,B,C,D)	A: L_{eq} 66.7-71.5dBA; B: L_{eq} 64.5-69.2dBA; C: L_{eq} 60.6-65.1dBA; D: L_{eq} 60.6-73.4dBA;	Office	N/A	Highly annoyed 16%; Highly annoyed 7.3%; Highly annoyed 13.3%; Highly annoyed 28.2%;
Liu, 2011[22]	Questionnaire+ environmental noise test	764	9:11	N/A	N/A	Residents within 6 kilometres from Hangzhou Xiaoshan Airport	L_{WECPN} 60-64.9dB; L_{WECPN} 65-69.9dB; L_{WECPN} 70-74.9dB; L_{WECPN} 75-79.9dB; L_{WECPN} ≥ 80dB	Outdoor	N/A	Highly annoyed 11.1%; Highly annoyed 20%; Highly annoyed 40%; Highly annoyed 57.1%; Highly annoyed 80%

Table 5 Measured data and predictions of aircraft noise in China's airports

Airport Name	Year	Measured Data	Affected Area/population	Predicted Results
Wuchang Nanhu Airport [42]	1986	L_{Amax} 82-112dBA (distance from the runway:0-3km)	L_{dn}>105dBA:1.26km^2; L_{dn} 100-104dBA:1.47km^2; L_{dn} 95-99dBA:3.25km^2; L_{dn} 90-94dBA:6.29km^2; L_{dn} 85-89dBA:10.08km^2; L_{dn} 80-84dBA:17.55 km^2	N/A
Tianshui Airport [43]	1987	L_{eq} 85-106dBA; L_{Amax} 89-102dBA; L_{WECPN} 71-93dB (distance from the runway:1-10km)	N/A	N/A
Shanghai Hongqiao Airport [44]	1991	N/A	L_{WECPN}>75dB: 22.5km^2/35,000 persons; L_{WECPN} 70-75dB: 23.5 km^2 / 25,000 persons	N/A
Sanming Shaxian Airport [45]	1994	N/A	N/A	2000 L_{WECPN}>70dB:5.94 km^2/800 persons ; L_{WECPN} >75dB:2.88 km^2/80 persons 2005 L_{WECPN}>70dB:9.83 km^2/1600 persons; L_{WECPN} >75dB:4.08 km^2/320 persons 2010 L_{WECPN}>70dB:15.23km^2/2800persons ; L_{WECPN} >75dB:5.88 km^2/800 persons
Shenyang Taoxian Airport [46]	1996	L_{Amax} 79.9-104.0dBA; L_{WECPN} 66.2-83.0dB (distance from the runway: 0.5-5km)	N/A	N/A
Guangzhou Baiyun Airport [47]	1998	Take-off: L_{Amax} 96.2-103.0dBA (distance from the runway: 0.45-3.5km) Landing: L_{Amax} 84.5-106.0dBA (distance from the runway: 0.45-3.5km)	L_{WECPN}>70dB: 400,000 persons (including the floating population)	2005 (after reconstruction) L_{WECPN}>85dB:92.20 km^2/13,500 persons L_{WECPN} 80-85dB:47.40 km^2/23,000 persons; L_{WECPN} 75-80dB:18.10 km^2/51,000 persons; L_{WECPN} 70-75dB:7.15 km^2/101,000 persons
One military airport in Zhenzhou [48]	2002	N/A	Annual average L_{WECPN}>80dB:2.46km^2; L_{WECPN} 75-80dB:11.48 km^2; L_{WECPN} 70-75dB:28.16 km^2 Busy season (June-September) L_{WECPN}>80dB:4.13 km^2; L_{WECPN} 75-80dB:15.29km^2; L_{WECPN} 70-75dB:32.96 km^2	N/A
Hefei Xinqiao Airport [49]	2007	N/A	N/A	2010 L_{WECPN}>85dB:1.84 km^2; L_{WECPN} 80-85dB:2.52 km^2; L_{WECPN} 75-80dB:5.71 km^2; L_{WECPN} 70-75dB:12.63 km^2; 2020 L_{WECPN}>85dB:2.37 km^2/0 persons; L_{WECPN} 80-85dB:3.42 km^2/129 persons; L_{WECPN} 75-80dB:8.52 km^2/1550 persons; L_{WECPN} 70-75dB:20.20 km^2/3664 persons
Shanghai Putong Airport [51]	2007	N/A	N/A	L_{WECPN}>85dB:11.42 km^2; L_{WECPN} 80-85dB:13.73 km^2; L_{WECPN} 75-80dB:32.77 km^2; L_{WECPN} 70-75dB:68.16 km^2
Chongqing Jiangbei Airport [52]	2008	L_{Amax} 68.3-92.5dBA L_{WECPN} 64.5-78.8dB (distance from the runway 0.49-3.7km)	L_{WECPN} ⩾85dB:1.62 km^2; L_{WECPN} 80-85dB:2.41 km^2; L_{WECPN} 75-80dB:5.63 km^2; L_{WECPN} 70-75dB:11.59 km^2	2015 L_{WECPN} ⩾85dB:4.12 km^2; L_{WECPN} 80-85dB:5.65 km^2; L_{WECPN} 75-80dB:11.29 km^2; L_{WECPN} 70-75dB:27.19 km^2 2020 L_{WECPN} ⩾85dB:6.5 km^2; L_{WECPN}80-85dB:8.2 km^2; L_{WECPN}75-80dB:16.9 km^2; L_{WECPN}70-75dB:31.1 km^2
Beijing Capital Airport [39]	2009	L_{Amax} 45-103.6dBA L_{dn} 51.4-72.5dBA L_{WECPN} 64.4-89.1dB (distance from the runway 0.07-11.10km)	L_{WECPN} 80-85dB:0.20 km^2/ 4,442 persons; L_{WECPN} 75-80dB:1.30 km^2/ 27,764 persons; L_{WECPN} 70-75dB:4.43 km^2/ 55,069 persons	

Table 6 International aircraft noise standards and regulations

Country	Noise indicator	Weighted time periods	Standard values (dB)		Restrictions
China	L_{WECPN}	3 periods (+5dB for evening , +10dB for night)	<70		Only special residential areas, cultural and educational areas
			70-75		Other living areas
USA	L_{dn}	2 periods (+10dB for night)	<65		No restrictions
			65-75		Restricted to build new housing, and soundproofing must be applied
			>75		New residential construction prohibited
Canada	NEF	2 periods (+12.2dB for night)	≤30		No restrictions
			30-40		Soundproofing must be applied in the new housing
			>40		New residential construction prohibited
UK	L_d, L_n	2 periods (daytime and night)	Daytime	Night-time	
			<57	<48	No restrictions
			57-66	48-57	Consider the noise impact in land-use and apply noise mitigation strategies when appropriate
			66-72	57-66	Normally new construction not permitted. If permitted, sufficient noise mitigation must be applied
			>72	>66	New residential construction prohibited
France	L_{den}	3 periods (+5dB for evening , +10dB for night)	50-55/57		No restrictions
			55/57-62/65		New residential construction permitted
			62/65-70		New residential construction permitted, only if the local government approves it
			>70		New residential construction prohibited
German	L_d	2 periods (daytime and night)	Newly-built airports	Existing airports	
			55-60	60-65	New noise sensitive building (hospital, school etc.) prohibited
			>60	>65	New residential construction prohibited, New noise sensitive building (hospitals, schools etc.) prohibited
Australia	ANEF	2 periods (+6dB for night)	<20		No restrictions
			25-25		Soundproofing must be applied in the new housing
			>25		New residential construction prohibited
Japan	L_{den}	3 periods (+5dB for evening , +10dB for night)	<57		Only special residential areas
			57-62		Other living areas