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ANNOYANCE RESPONSE TO AIRCRAFT NOISE EXPOSURE: A CASE STUDY CARRIED OUT IN BRAZIL

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Abstract: This study reports the first effort to assessment of community annoyance caused by aircraft noise exposure in Brazil. The purpose of this study is to assess the exposure-effect relationship for aircraft noise in Brasília. The percentages of people who felt annoyed and highly annoyed have been used to assess the dose-response and both were obtained using a survey. The survey was sent by e-mail and was carried out among residents in the vicinity of Brasília International Airport. The questionnaire contained questions about: personal data, noise annoyance and interference with daily activities. The question relating to the aircraft noise annoyance was answered on an 11-point numerical scale. In total, 402 participants responded, with 51% female and 49% male. Logistic and polynomial approximations of the exposure-annoyance relationships for the year 2016 are presented for the DNL and L_{den} noise metrics. The results show that for the same noise exposure, the aircraft noise annoyance in Brasília is higher than those reported in the European Community. Finally, the dose-response models developed in this study contribute to a better understanding of the impact of aircraft noise in populated areas around airports in Brazil.
Keywords: Aircraft noise, Community noise, Dose-response relationships.

INTRODUÇÃO

Airports are vital components of the transport infrastructure of modern cities and exert increasing influence on urban zoning. However, they are responsible for environmental externalities such as the harmful effects on human health caused by noise, such as annoyance, hypertension, heart problems, psychological and emotional problems, stress, and illnesses associated with sleep disorders (Babisch, W., 2002; Jarup, L., 2005; Haralabidis A. S., 2008; Babisch, W et al., 2009). Aircraft noise also negatively affects people's perception of well-being and satisfaction in inhabiting a region contributing to conflicts between airport operators, local governments, and the community (Kroesen, M., 2010, Faburel, G., 2005; De Barros A. G., 2013).

Annoyance is widely accepted as a basis for evaluating the impact of noise on an exposed population (WHO, 2011; Directive 2002/49/CE, 2002). However, the difficulty is estimating the annoyance perceived by communities exposed to aircraft noise. World Health Organization (WHO) and the European Community (EC) recommend a methodology based on dose-response models to relate a noise level (dose) with a degree of noise annoyance (response/effect). The results of these relationships allow quantifying the percentage of annoyed people (%A) and the percentage of highly annoyed people (HA%) with aircraft noise (WHO, 2011; EC, 2002).

Currently, the percentage of highly annoyed people (HA%) is used as an indicator of noise annoyance in North America, Australia, and the European Community. (WHO, 2001; EC, 2008; Schultz, T.J., 1978; Miedema, H.M.E and Vos, H., 1998; Finegold, L. S.; Harris, C. S.; Gierke, H. E., 1994; EEA, 2010). WHO also recommends the determination of %HA as one of the environmental health indicators needed to assess the adverse health effects of environmental noise, including being recommended for the long-term management of noise from the road, rail, and air traffic sources (WHO, 2011; EC, 2002).

Many social surveys have been developed for the elaboration of dose-response models between noise levels and noise annoyance, mainly in Europe and North America (Schultz, T.J., 1978; Miedema, H.M.E e Vos, H.1998; Fields, J. M.,1993; Fidell, S., Barber D.S. e Schultz, T.J., 1991; Miedema, H. M.E e Oudshoorn, C. G., 2001). In Brazil, the number of researches related to the impacts of aeronautical noise has increased during the last decade. However, none of these Brazilian researchers proposed a dose-response model for evaluating the reaction of communities exposed to airway noise around a Brazilian airport (Carvalho Jr, E. B, 2015).

Therefore, this study marks the first effort to assess the impact of aeronautical noise, through dose-response relationships, on exposed communities around a Brazilian airport. The objective was to develop a representative dose-response model for the annoyance caused by aircraft noise at Brasília International Airport and compare it with models from other countries.

MATERIAL AND METHODS

To assess the annoyance level, noise curves simulations and social survey have been carried out in community exposed to aircraft noise. The survey is designed according to the "Conference Reporting Guidelines" which were previously suggested by Fields et al. (1997), and newly updated in 2009 by the Community Response Team of International Commission on the Biological Effects of Noise (ICBEN).

SOCIAL SURVEY

Social surveys of the community response to aircraft noise were conducted around Brasilia International Airport in Brasília, capitol of Brazil. After preparing the questionnaire, a pre-test was carried out with the application of 50 instruments. Data from these questionnaires were analyzed, questions were corrected and others were eliminated. Thus, the adapted questionnaire was sent by e-mail to 3600 residents of cities within noise curves at the limit of $50 \leq DNL \leq 70$. The reliability of the questionnaire was measured using Cronbach's alpha (a) test. Of the 3600 questionnaires sent, 931 (26%) were answered and 402 were validated.

In the questionnaire, annoyance caused by aircraft noise exposure has been investigated and the percentage of respondents who felt highly annoyed (%HA) was assessed. Respondents were asked to answer the question, 'Thinking about the last 12 months or so, what number from 0 to 10 best shows how much are you bothered, disturbed, or annoyed by aircraft noise?'. A numerical scale from 0 (not annoyed at all) to 10 (extremely annoyed) was used in the survey and for the responses of exceeding 7, it is defined as the highly annoyed population.

Logistic regression (RL) was carried out to generate the dose-response models. The variables "highly annoyed" (HA) and "annoyed" (A) were calculated as binary data and as a dependent variable. The predicted values, in the acoustic maps, for DLN and Lden were chosen as independent variables. Statistical analyzes were performed with SPSS 20.

NOISE CURVES

Simulations were carried out in the acoustic metrics DNL (day-night level) and Lden (day-evening-night) using the INM 7.0d. Noise map was elaborated with QGIS 3.16. The generated noise curves represent the operation for 2017, where 202,000 operations per year, of landings and take-offs, and an average of 553 daily movements were estimated.

RESULTS

QUESTIONNAIRE RESULTS AND SIMULATED NOISE CURVES

The result obtained for the Cronbach's alpha (a) test was 0.902. Values above 0.75 are considered high, indicating a high level of reliability of the questionnaire (Bisquerra, R., Sarriera, J. C e Francesc, M., 2004).

Figure 1 shows the noise map and the location of the questionnaire application areas. In this figure, it is possible to visualize a large population density inside the curves included in the limits 50 < DNL ≤ 60. Residents inside these curves, mainly in the DNL 60, feel highly uncomfortable with the airway noise (Carvalho Júnior, E. B.; Garavelli, S. L.; Maroja, A. M., 2012).

About 51% of respondents were female and 49% male. The variable age (mean = 29; median = 25) was distributed as follows: 18 - 20 years (21%), 21 - 30 (47%), 31 - 40 (17%), 41 - 50 (9%) and 51 – 60 years old (6%). There is a concentration of ages between 21 and 40 years and a high number of respondents with higher education and postgraduate degrees. The percentages for this variable are defined as follows: 1% have primary education, 15% have secondary education, 66% have higher education and 18% indicated that they have a postgraduate degree. Figure 2 shows the combination of the distribution of respondents by age, sex and level of education. Women have more education than men at higher education and postgraduate level.

Table 1 indicates the percentage of people annoyed by aircraft noise. 26% of respondents are annoyed (A) and 36% highly annoyed (HA) in DNL 65. In DNL 60, there is 23% of HA and 13% of A. In DNL 55, 12% of HA and 18% A and in DNL 50 a total of 9% HA and 13% A. As expected, the percentage of annoyed for the noisier curves (DNL 60 and DNL 65) is higher than for the less noisy curves (DNL 50 and DNL 55). In the DNL 65, the percentage of HA is four times higher than in the DNL 50. It was verified that the level of annoyance is perceived differently by the respondents in the different noise curves.

Figure 3 shows the combination of the distribution of the 'age', 'sex' and 'Annoyed' variables. For women and men, there is a small variation between the classification annoyed and not annoyed with very close medians. Men between 30 and 50 years are slightly more annoyed with aircraft noise than women. For 'age', 'gender' and 'Highly Annoyed' (Figure 4) a greater variation was found between the classification highly annoyed and not annoyed with more distant medians, for both women and men. In the age range 20 – 40 years women are more highly annoyed than men. However, in the range 40 – 50 years for men, the perception of being highly annoyed is slightly higher.

Table 2 shows the results of the level of annoyance caused by aeronautical noise in daily activities. In the noisiest locations (DNL 60 – 65) the percentages of people annoyed and highly annoyed by aeronautical noise, when performing daily activities, are higher than in regions under the less noisy curves (DNL 50 – 55). It was also verified the existence of highly significant correlations (p = 0.000) between the levels of annoyance and the levels of aircraft noise.

Results, shown in Table 2, are corroborated by other studies. Lam et al. (2009) have found that aircraft noise strongly disturbs routine activities such as sleeping, watching TV, and concentrating. Schreckenberg et al. (2010) confirm that aircraft noise causes high annoyance and disturbances in daily activities performed inside or outside homes. Carvalho Jr et al. (2012) concluded that aircraft noise can significantly interfere with communication between people, concentration on writing and reading activities, sleep, and can cause startle (fright).

Respondents also answered how much aircraft noise bothered them during the day and at night. Table 3 shows the results obtained for the DNL 60 – 65 and DNL 50 – 55. The percentage of highly annoyed (HA) in the DNL 60 - 65 was higher during the day than at night. For DNL 50 - 55 the HA level was slightly higher in the evening (21%) than in the daytime (18%). The correlations obtained are highly significant (p = 0.000) showing

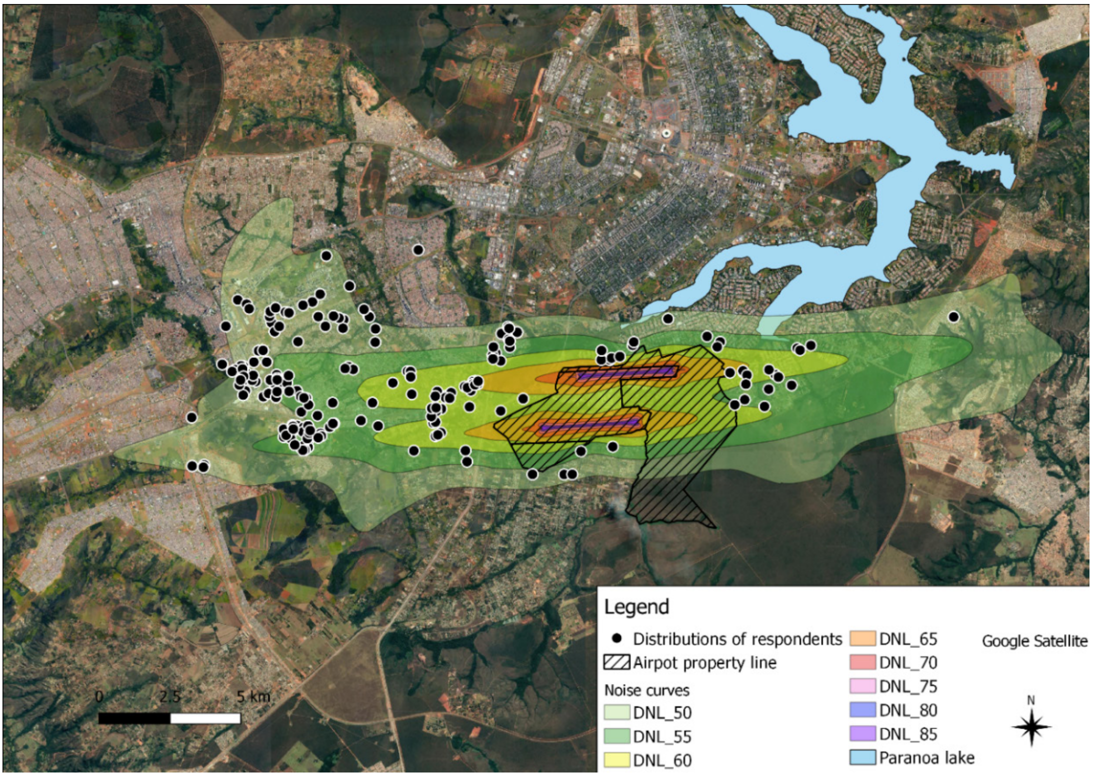

Figure 1. Location of the survey respondents around Brasília Int'l Airport

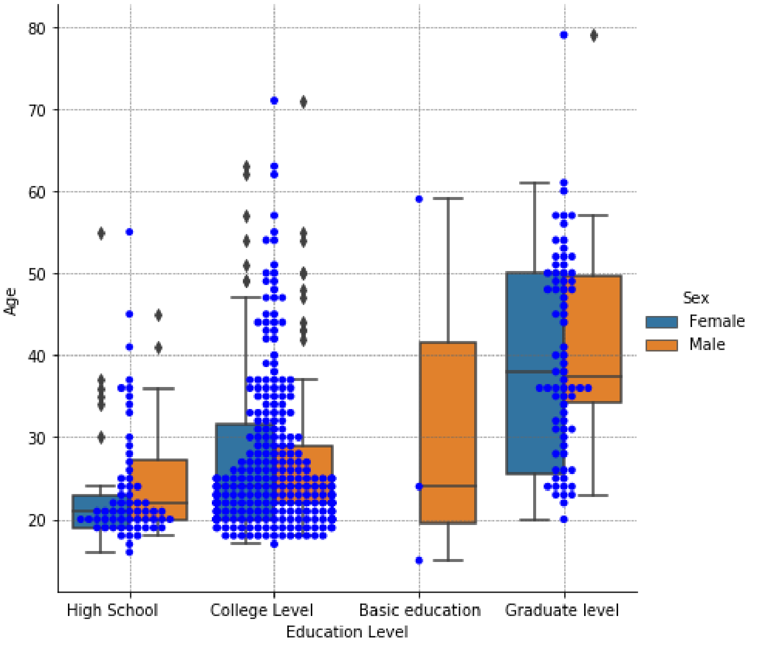

Figure 2. Combination of distribution – Age, Sex and Education Level

Annoyance level	DNL				% of Total	$x^2(9)$	ρ Spearman
	50	55	60	65			
Not annoyed	16%	18%	13%	5%	15%	28,456 p = 0,001	0,226 p = 0,000
Little annoyed	63%	53%	51%	33%	53%		
Annoyed	13%	18%	13%	26%	16%		
Highly annoyed	9%	12%	23%	36%	16%		

Table 1: Aircraft noise annoyance level for each DNL

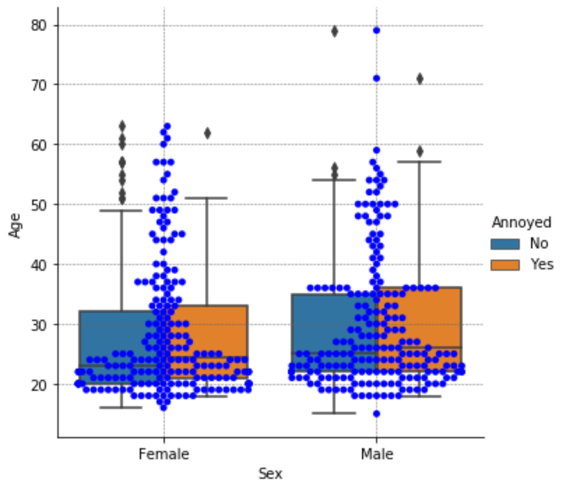

Figure 3. Combination of distribution – Age, Sex and Annoyed

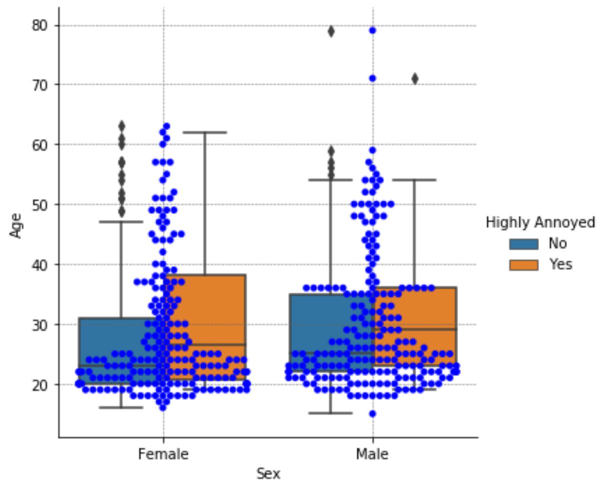

Figure 4. Combination of distribution – Age, Sex and Highly Annoyed.

Everyday activities	Annoyance level	Aircraft noise	
		DNL 50-55 n = 288	DNL 60-65 n = 114
reading/studying	Annoyed	15%	17%
	Highly annoyed	27%	32%
	Pearson correlation (r)	0,586; p = 0,000	0,430; p = 0,000
watching TV	Annoyed	13%	13%
	Highly annoyed	21%	38%
	Pearson correlation (r)	0,548; p = 0,000	0,581; p = 0,000
talking on the phone	Annoyed	16%	14%
	Highly annoyed	23%	44%
	Pearson correlation (r)	0,564; p = 0,000	0,567; p = 0,000
sleeping	Annoyed	6%	6%
	Highly annoyed	20%	26%
	Pearson correlation (r)	0,388; p = 0,000	0,366; p = 0,000
meditating/praying	Annoyed	10%	10%
	Highly annoyed	21%	18%
	Pearson correlation (r)	0,479; p = 0,000	0,382; p = 0,000

Table 2: Annoyance level with aircraft noise in everyday activities

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higher correlations for the daytime period. So, for both periods, if aircraft noise levels increase the annoyance levels also increase.

Table 4 expresses the answers referring to the respondents feeling uncomfortable when awakened/awake in the middle of the night by the air traffic noise. For the regions under the noisiest curves (DNL 60 – 65), the total percentage of bothered and highly annoyed is 61%. For the regions under the less noisy curves (DNL 50 -55) the total percentage is 53%, that is, the respondents were more disturbed, when awakened by the aeronautical noise, in the regions under the DNL 60 - 65 curves. It must be noted that the percentages of bothered, in the most and least noisy curves, indicate that when the respondent is awakened, the level of discomfort is high.

An analysis was carried out between the gender of the respondents and the level of annoyance with awakening/waking up to aeronautical noise. Of those surveyed, 47% of men and 53% of women indicated that they felt highly annoyed by aircraft noise when awakened in the middle of the night. Female respondents feel more uncomfortable than males when awakened in the middle of the night.

DOSE-RESPONSE RELATIONSHIPS

Table 5 summarizes the logistic functions generated in this study for the acoustic metrics DNL and Lden. The p-value was lower than the significance level in all cases, that is, parameters â0 and â1 are significant in the model.

With the functions expressed in Table 5, the dose-response curves presented in Figure 6 were generated. The dose-response curve of the European Community is also presented for comparison purposes.

Table 6 expresses the functions developed in this study and in different countries for the dose-response relationship between %A, %HA and the DNL and Lden metrics. Figure 8(a) shows the comparison between the result curve of the present study and the curves of Schultz (1978), Fidell et al. (1991) and Finegold et al. (1992) synthesized to represent the percentage of highly disturbed people due to noise from the main transport sources (air, road and rail). It is possible to verify that the level of annoyance, among those surveyed in regions around the Brasília Airport, is higher than that predicted in the curves of these authors.

In the United States, the FAA (Federal Aviation Administration) adopts these dose-response relationships as the main basis for guidelines related to the compatibility of sound zoning with land use and occupation. However, the FAA recognizes that these dose-response relationships are outdated, as recent research in several countries has shown significantly different results from these models. This way, the FAA initiated a large survey, to be carried out in 20 airports, for the development of updated dose-response models (Miller, N., Sizov, N., Lohr, S and Cantor D, 2014).

Figure 8(b) expresses the comparison with the EC curve (2002) and studies developed in Switzerland for the Zurich airport. Like the Swiss dose-response curves, 2001 and 2003, the Brazil curve (2015) indicates a higher level of discomfort than the EC predictive curve. Figure 8(c) shows that the Brazil curve (2015) expresses a lower level of discomfort than that perceived in the study of Japan and China. Up to DNL 55, Japanese respondents showed a lower level of discomfort than Chinese respondents and from this limit, Chinese respondents were more uncomfortable.

Figure 8(d) shows the synthesis curves for the Lden metric. It is observed that the curves obtained in Switzerland, Vietnam and Brazil (2015) express a higher level of discomfort than that predicted in the EC curve. Up to

Period	Annoyance level	Aircraft noise	
		DNL 50-55 n = 288	DNL 60-65 n = 144
Daytime: 07h – 22h	Annoyed	15%	16%
	Highly annoyed	18%	33%
	Pearson correlation (r)	0,672 p = 0,000	0,644 p = 0,000
Nightly: 22h – 07h	Annoyed	9%	11%
	Highly annoyed	21%	27%
	Pearson correlation (r)	0,516 p = 0,000	0,568 p = 0,000

Table 3. Annoyance level per period

The person wakes up/wakes up in the middle of the night	NII	DNL 50-55 n = 288	DNL 60-65 n = 144	χ (3)
aircraft noise	I	10%	15%	3,47 p = 0,325
	AI	43%	46%	
	P	0,336 0,000*	0,277 0,003*	

Note: NI: Not Disturbed / PI: Slightly Disturbed / I: Disturbed / AI: Highly Disturbed / NII: Level of Discomfort / * p-value / ñ = Spearman correlation

Table 4. Level of annoyance when awakened by aircraft noise

$\%HA = \frac{100}{1+e^{(8,845-0,127DNL)}}$	β_1= 0,127 p. 0,000 / S.E = 0,030 β_0 = - 8,845 p. 0,000 / S.E = 1,749 I.C (95%): Inferior = 1,069 / Superior = 1,205
$\%A = \frac{100}{1+e^{(6,617-0,105DNL)}}$	β_1= 0,105 p. 0,000 / S.E = 0,025 β_0 = - 6,617 p. 0,000 / S.E = 1,393 I.C (95%): Inferior = 1,058 / Superior = 1,165
$\%HA = \frac{100}{1+e^{(8,862-0,125L_{den})}}$	β_1 = 0,125 p. 0,000 / S.E = 0,034 β_0 = - 8,862 p. 0,000 / S.E = 1,964 I.C (95%): Inferior = 1,061 / Superior = 1,211
$\%A = \frac{100}{1+e^{(6,039-0,093L_{den})}}$	β_1 = 0,093 p. 0,000 / S.E = 0,028 p. 0,000 β_0 = - 6,039 p. 0,000 / S.E = 1,590 I.C (95%): Inferior = 1,039 / Superior = 1,159

Table 5: Generated logistic functions

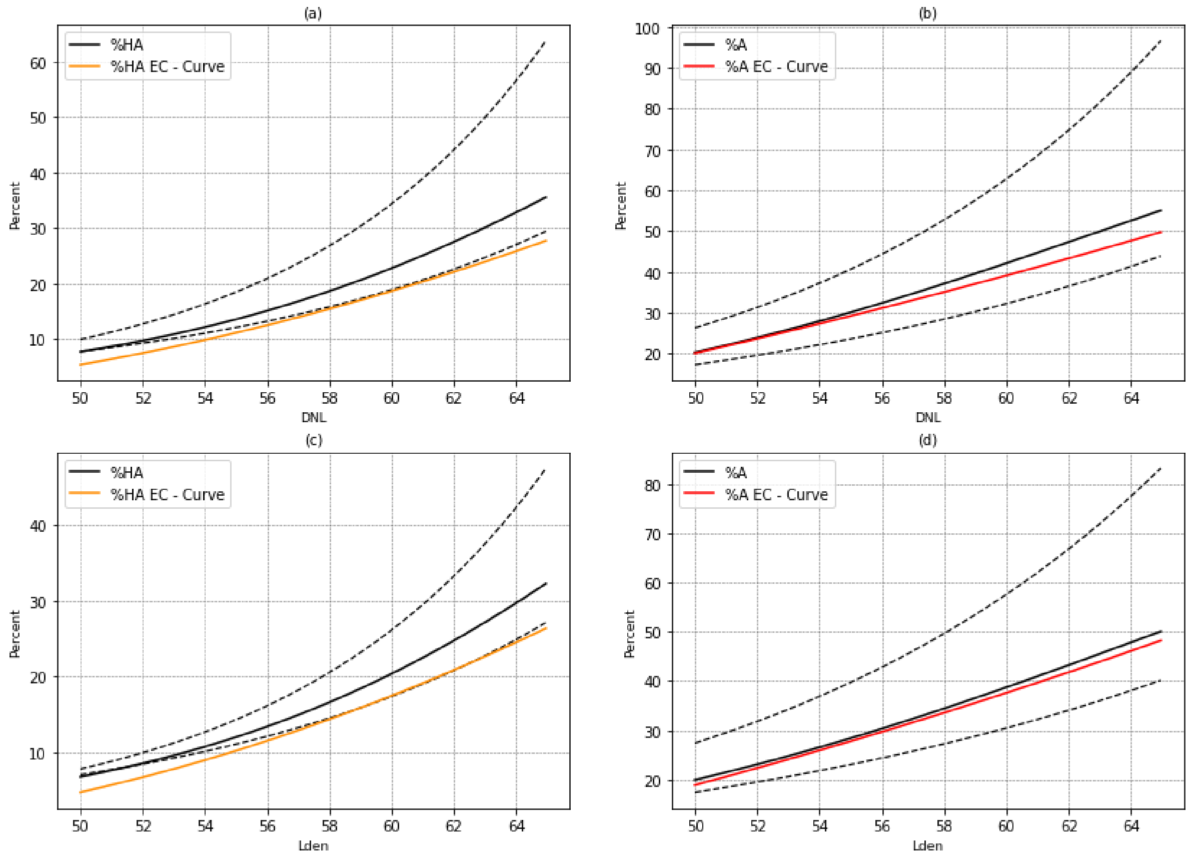


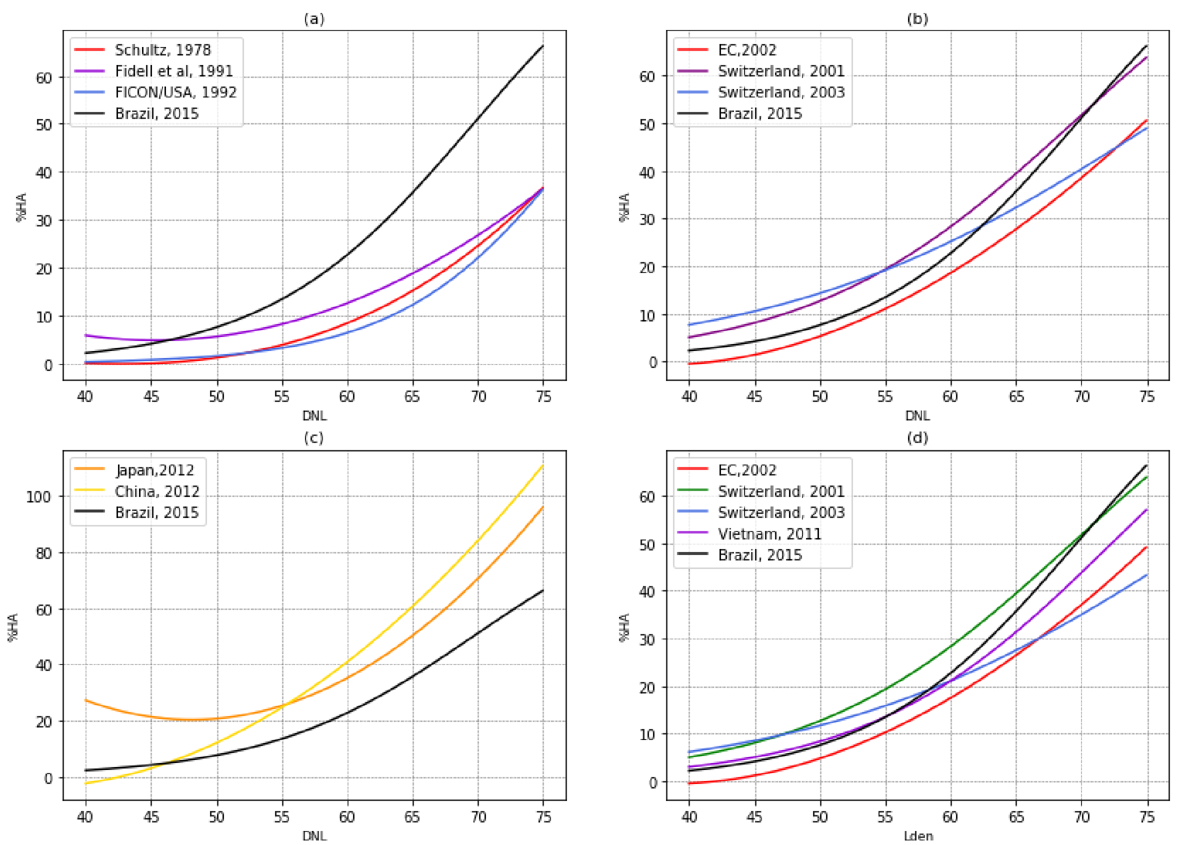
Figure 6. Online color means annoyance %A and highly annoyed _%HA_ due to DNL and *L*den, with confidence limits of 95%. N=402. The EU European Commission, 2002 curve for %A and %HA is shown for comparison.

North America and Europe	
Schultz (1978) [a]	$\%HA = 0,8553 \times DNL - 0,0401 \times DNL^2 + 0,00047 \times DNL^3$
Fidel et al. (1991) [a]	$\%HA = 78,9181 \times DNL - 3,2645 \times DNL + 0,0360 \times DNL^2$
Finegold et al. (1992 apud FICON, 1992) [a]	$\%HA = \dfrac{100}{1+e^{(11,13-0,141DNL)}}$
Europe	
European Commission (2002) [b]	$\%A = 1,460 \times 10^{-5}(DNL-37)^3 + 1,511 \times 10^{-2}(DNL-37)^2 + 1,346(DNL-37)$ $\%HA = -1,395 \times 10^{-4}(DNL-42)^3 + 4,081 \times 10^{-2}(DNL-42)^2 + 0,342(DNL-42)$ $\%A = 8,588 \times 10^{-6}(L_{den}-37)^3 + 1,777 \times 10^{-2}(L_{den}-37)^2 + 1,221(L_{den}-37)$ $\%HA = -9,199 \times 10^{-5}(L_{den}-42)^3 + 3,932 \times 10^{-2}(L_{den}-42)^2 + 0,2939(L_{den}-42)$

Switzerland (2001) [c]	$\%A=\frac{100}{1+e^{(6,03-0,10DNL)}}$ $\%HA=\frac{100}{1+e^{(6,93-0,10DNL)}}$ $\%A=\frac{100}{1+e^{(5,78-0,09Lden)}}$ $\%HA=\frac{100}{1+e^{(6,93-0,10Lden)}}$
Switzerland (2003) [c]	$\%A=\frac{100}{1+e^{(4,54-0,07DNL)}}$ $\%HA=\frac{100}{1+e^{(5,29-0,07DNL)}}$ $\%A=\frac{100}{1+e^{(4,64-0,08Lden)}}$ $\%HA=\frac{100}{1+e^{(5,52-0,07Lden)}}$
Ásia	
Japan (2012) [d]	$\%HA = 0,105\times(DNL)^2-10,103\times DNL+263,31$
China (2012) [e]	$\%HA = 0,072\times(DNL)^2-5,036\times DNL+83,810$
Vietnam (2011) [f]	$\%HA = \frac{100}{1+e^{(7,741-0,107Lden)}}$
South America	
Braszl (2015) [g]	

a: result obtained from the analysis of databases from different countries in North America and Europe; b: European Community (studies developed by Miedema and Oudshoorn (2001) in the Netherlands) c: Brink et al., (2008); d: Yamada, 2012; e: Guoqing et al., 2012 / f: Nguyen et al. (2011) / g: Study Result

Table 6. Functions adopted to compare %I, %AI and DNL



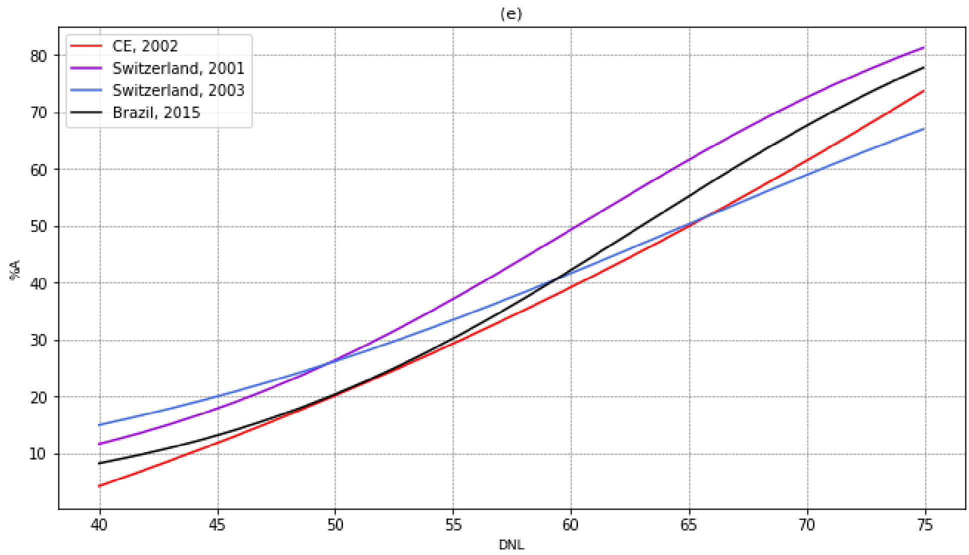


Figure 8. Comparison between noise curves

Noise Curve	%HA		%	%A		Dif%
	RE	CE		RE	CE	
DNL 50	7,6	5,3	30%	20,3	20,0	1%
DNL 55	13,5	11,0	19%	30,1	29,2	3%
DNL 60	22,7	18,6	18%	42,1	39,1	7%
DNL 65	35,7	27,8	22%	55,2	49,8	10%
DNL 70	51,1	38,5	25%	67,5	61,3	9%

RE = study result / EC = European Community / Dif% = Percentage difference / Source: Carvalho Jr, 2015

Table 7. %HA and %A determined for each noise curve

DNL 60, the curves for Vietnam, Switzerland 2003 and Brazil 2015 are similar and from DNL 65 onwards, the levels of annoyance of respondents in the surroundings of Brasília Airport are higher than those of respondents in surveys from Vietnam and Switzerland 2003, being surpassed only by the result of the Swiss 2001 curve. Figure 8(e) shows the comparison of the %A curves as a function of the DNL, with the %A Brazil 2015 curve being higher than the EC predictive curve after the DNL 55 limit and lower than the curve obtained for Switzerland 2001 and 2003 up to the limit DNL 60. After this limit, the respondents' perception of discomfort in the surroundings of Brasília Airport is higher than the result of Switzerland 2003 and lower than the result of Switzerland 2001

From the comparisons made between the different studies, it can be observed that moderate levels of noise generate accentuated levels of annoyance due to aeronautical noise. There is an increase in the level of annoyance from exposure to aeronautical noise, which indicates a tendency for people to perceive airborne noise more intensely in recent decades, as well as showing the need for the synthesis curves, adopted in the EC, to be updated (Babisch W., et al., 2009; Guski, R., 1999; Schreckenberg, D., et al. 2010; Kamp, I van, 2004; Kempen, E.E.M.M. van and Kamp, I. van, 2005.

The percentage of people highly annoyed and annoyed by aircraft noise, obtained in this study, was higher than the level of annoyance predicted by dose-response curves used for noise from traffic sources in general (Schultz, T.J., 1978; Finegold, L. S, Harris, C. S and Gierke, H. E., 1994; Fidell, S., Barber D.S. and Schultz, T.J., 1991) and also for noise specific to aircraft operation, such as the curves used by the EC and WHO (Directive 2002 /49/CE, 2002; EC, 2002).

In Table 7, by way of comparison, the percentages obtained with the logistic functions generated in this study and the percentages determined with the EC functions are expressed. It is noted that the percentage of highly annoyed people (%HA), in the surroundings of Brasília Airport, is significantly higher than the percentages predicted in the EC. For example, it is 30% higher for DNL 50 and 25% more for DNL 70. For the percentage of troubled people (%I), this difference is smaller, being 10% for DNL 65 and 9% for DNL 70.

CONCLUSIONS

This study provided a broader understanding of the reaction of communities exposed to aircraft noise in Brazil. It was found that the most disturbed respondents inhabit areas of the city under the noise range DNL 55 - 65. It is also found that aeronautical noise significantly interferes in the performance of daily activities of the respondents, such as studying, sleeping, watching TV, talking on the phone and meditate. This interference occurs both during the day and at night, with the potential to negatively impact the quality of life and well-being of the exposed population.

Those surveyed, in all age groups, presented considerable levels of annoyance with aeronautical noise, and the higher the age group, the higher the level of annoyance. In addition, when the respondent is awakened during the night, the level of discomfort is high, with the female respondents being more disturbed than the male ones.

Dose-response relationships were elaborated and showed that the percentage of annoyed and highly annoyed respondents, in the surroundings of Brasília International Airport, is higher than the percentages predicted by the dose-response curves used in the European Community and lower than that perceived in countries such as Japan and China. Therefore, it can be concluded that the models adopted in other countries cannot adequately estimate the level of noise annoyance felt by populations exposed to aeronautical noise in Brazil. Thus, the importance of developing specific models for the Brazilian reality is highlighted.

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