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Sound environmental impact resulting from the operation of aircraft at Santos Dumont Airport – Rio de Janeiro

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ABSTRACT

The operation of aircraft produces negative environmental externalities, such as air pollution and aeronautical noise that impacts the areas near airport sites, becoming a major source of conflicts between communities and airport operators. Noise discomfort from exposure to airborne noise affects health, quality of life and sleep. Thus, it is important to conduct research that seeks to evaluate the impact of aeronautical noise in the surroundings of airports. Thus, in the present work the sound impact caused by aeronautical noise in areas surrounding Santos Dumont airport (SBRJ) in the State of Rio de Janeiro was evaluated. The methodology was based on simulations of noise curves in the acoustic metric DNL (day-night level) using the INM 7.0d software. The input data required for the simulations were provided by INFRAERO for the year 2016. With the noise curves, acoustic maps were elaborated with the aid of the QGIS 2.18 software. The population exposed to air noise in different noise curves was also determined. In addition, a comparison was made between the methodologies currently used in Brazil and in the European Community to determine the percentage of people who were bothered (%I) and highly bothered (%AI) in the different noise curves. The results indicate that the percentage of disturbed in each noise curve is small when related to the number of inhabitants per neighborhood and it is concluded that for a better evaluation of the impact of aeronautical noise, RBAC 161 (2013) can be complemented with the calculation of the exposed population with its percentages of bothered and highly bothered people.

Keywords: Aeronautical noise, Sound nuisance, Sound zoning, Noise maps.

1 INTRODUCTION

Airports provide a great integration between agility and security related to the transport of passengers and cargo. They are also responsible for the generation of jobs, socioeconomic development, growth of cities and important agents inducing tourism. Although air transport is an important one for socio-economic development, it is also responsible for the generation of externalities such as noise pollution, air pollution, soil and water pollution, and problems caused by aeronautical accidents.

The main cause of air pollution from aircraft is due to the use of fossil fuel kerosene. The burning of this fuel causes several dangerous pollutants, contributing to global warming. Noise pollution, on the other hand, generates a nuisance to the populations that live near the airports and is one of the main impacts caused by air actions [1], and can generate not only irritation, but also adverse health effects such as hypertension, heart problems, sleep disorders, psychological, stress and emotional problems [2].

Thus, aeronautical noise stands out as one of the main externalities associated with airport operation. In this study, the environmental sound impact resulting from the operation of aircraft at Santos Dumont Airport in Rio de Janeiro was evaluated. The specific objectives were: to simulate noise curves for Santos Dumont airport, to classify land use around Santos Dumont aerodrome as indicated in RBAC 161/2013 [3] and to estimate the amount of population exposed to aeronautical noise in the surroundings of Santos Dumont Airport.

2 THEORETICAL FRAMEWORK

Aeronautical noise is all noise coming from aircraft support tools and their own operation. Aeronautical noise directly affects the quality of life of people living around the airfields, and for this reason it is considered the main environmental problem caused by the operation of airports. For the WHO, aeronautical noise is considered the third type of pollution that most affects man [4]. Each airport generates noise at different intensities, as it depends on the amount of landings and takeoffs, the aircraft models, the ground equipment that supports the aircraft, and the procedures of the airports.

To determine the aeronautical noise level the RBAC 161 (2013) [3] indicates the use of the acoustic metric Ldn or DNL (*Day Night Level),* as demonstrated by the following formula 1. The degree of sound discomfort measured by this method is determined for 24h, but in the period between 22h and 7h, 10 dB of the penalty is added to all levels. Where the number 24 corresponds to the hours measured, 15 to the interval of the day and 9 at night. Following the rules of the period from 22h to 7h.

$$L_{dn} = 10 \times \log\left[\frac{1}{24}\left(15 \times 10^{\frac{L_d}{10}} + 9 \times 10^{\frac{(L_n+10)}{10}}\right)\right] \quad (1)$$

Sound discomfort, according to the WHO, is considered one of the main risk factors to health and is one of the environmental indicators that require the evaluation of the improper effects on health caused by environmental noise [5]. The main causes of noise nuisance come from traffic, if compared to rail and road traffic noise, aircraft noise is the most bothersome, according to a study by Miedema and Oudshoorn [5].

2.1 LEGISLATION

The legislation aims to standardize the operations of airfields and the use of land in their surroundings. In this way, the standards created are important mechanisms for the improvement of the conditions of service aimed at the well-being of the population.

2.1.1 Brazilian Civil Aviation Regulation (RBAC) No. 161 of 2013

The most recent Brazilian legislation that refers to aeronautical noise, establishes the need for the elaboration of an Aerodrome Noise Zoning Plan (PZR). It also presents the compatibilizations and incompatibilizations in relation to land use defined for the areas demarcated by the curves. The Noise Zoning Plan (PZR) of an airport, according to the RBAC [3] is a document whose purpose is to geographically represent the area affected by the impact of aeronautical noise, composed of the noise curves and the compatibilizations and incompatibilizations to the land use established for the areas delimited by these curves. Noise curves are lines drawn on a map, each representing equal levels of noise exposure.

The Specific Noise Zoning Plan (PEZR) determines that the five noise curves must be calculated through a mathematical methodology suitable for the generation of curves in the *DNL* metric by means of a computer program. The PEZR can be requested by ANAC to any aerodrome, but it is required of airports with large aircraft movements (more than seven thousand movements / year) and / or that have occupations of their surroundings with uses incompatible with aeronautical noise. The PBZR (Basic Noise Zoning Plan) has noise curves of 75 to 65 dB with simplified geometric shapes, with pre-configured curves, the plan is applied to airports with less aircraft movement (less than seven thousand movements / year) [6]. Its noise curves are obtained by framing each airfield runway in one of four classes considering the number of aircraft movements in the previous year.

2.1.2 Directive 2002/49/EC

The methodology described in Directive 2002/49/EC [5] has the main objective of relating environmental noise, and aeronautical noise, with the harmful effects on the population exposed to noise, including noise nuisance and sleep disturbance. From the determination of these effects, the necessary plans for sound zoning are elaborated, always with the purpose of preserving human health and the quality of the acoustic environment. In general, the methodology adopted in the European Community allows obtaining information that better guides the development of a sound zoning. To determine the level of discomfort and the level of disturbance in sleep, the integration of acoustic maps and dose-response evaluations is used for a broader understanding of the impact generated by noise in the areas near the airport.

3 METHOD

3.1 AREA OF STUDY

For this study, we considered the Santos Dumont Airport of Rio de Janeiro, whose acronym ICAO (*International Civil Aviation Organization*) is SBRJ. Since its inauguration, the SBRJ has already undergone some renovations, one of them due to a fire that occurred in 1998 that destroyed the airport, taking months for its reconstruction, and in 2007 a new airport terminal was inaugurated, which was able to double the capacity for about nine million passengers per year [7]. Santos Dumont Airport is located in the center of Rio de Janeiro and is the second in the country in the ranking by movement of aircraft on domestic flights and passengers, data presented from the Operational Statistical Yearbook [8]. The airport has two parallel runways, 20L/02R and 20R/02L, with wheelbases of 75m, not allowing simultaneous actions. Figure 1 represents the location of the airport, and Table 1 presents the characterization of the airport.

Figure 1: SBRJ Location (Google Earth)

Table 1: Airport Characterization

Aerodrome Name	Santos Dumont Airport – RJ
Airport Operator	INFRAERO
ICAO Designator	SBRJ
IATA designator	SDU
City	Rio de Janeiro
State	Rio de Janeiro
Geographical coordinates of the aerodrome	S22° 54', W43° 09'
Aerodrome elevation	3,048m
Reference temperature	30.4°C

Source: Aerodrome Chart (ADC) [9]

3.2 METHODOLOGY, UNITS AND INDICES

The noise curves were generated through the *INM* 7.0d (*Integrated Noise Model*) software, developed by the FAA (*Federal Aviation Administration* – USA), using the DNL metric for quantification and analysis of the corresponding intensity. The curves were simulated for the year 2016 with a total operation (landings + takeoffs) of 105,000 [10]. The aircraft used in the simulations are shown in Table 02. These equipments are the ones that operate the most, percentageally in the SBRJ.

Table 2: Operation estimation by equipment

Equipment	Estimated operating percentage per equipment (year 2016)
Cessna Citation C550	2
Airbus A319	34
AT72	4
Boeing 737700	12
Boeing 737800	23
Embraer E190	11
Embraer E195	14
TOTAL	100

The SBRJ operation data, used in the simulations of the noise curves, are indicated in Tables 3, 4 and 5.

Table 3: Percentage of headwater operations in 2016

Percentage of headwaters operations 2016		
Headboard	**%Landing**	**% Takeoff**
02R	28.00%	0.00%
20L	72.00%	70.00%
02L	0.00%	0.00%
20R	0.00%	30.00%
TOTAL	100.00%	100.00%

Table 4: Total landings per headboard

Total Landings					
Landing	**02R**	**02L**	**20R**	**20L**	**Total**
2016	15039	15	4	37779	52837
	28%	0%	0%	72%	1
	19%	0%	0%	48%	67%
	9%	0%	0%	24%	33%

Table 5: Total takeoffs per headboard

Total Takeoffs					
Takeoffs	**02R**	**02L**	**20R**	**20L**	**Total**
2016	15769	24	1	36941	52837
	30%	0%	0%	70%	1
	20%	0%	0%	47%	67%
	10%	0%	0%	23%	33%

From the IBGE census survey (2010 Census) it was possible to calculate the exposed population, processed in the programs QGIS (*GIS Software* – version 2.18) and Microsoft Office Excel. To avoid overestimation of the results, the overlapping and intersection of each noise curve was performed separately and then the values were subtracted from the largest curve [5]. Through calculations developed by Carvalho Júnior [5] for Brasília Airport, the approximate percentage of people Disturbed (%I) and Highly Bothered (%AI) with aeronautical noise is obtained. Annex I shows the algorithms, derived from dose-response studies, used to determine and compare the percentage of people who are bothered (%I) and highly bothered (%AI).

Brazil (2015) *

$$\%I = \frac{100}{1 + e^{(6,617 - 0,105 DNL)}} \tag{1}$$

$$\%AI = \frac{100}{1 + e^{(8,845 - 0,127 DNL)}} \tag{2}$$

European Community (2002)*

$$\%I = 1,460 \times 10^{-5}(DNL - 37)^3 + 1,511 \times 10^{-2}(DNL - 37)^2 + 1,346(DNL - 37) \tag{3}$$

$$\%AI = -1,395 \times 10^{-4}(DNL - 42)^3 + 4,081 \times 10^{-2}(DNL - 42)^2 + 0,34(DNL - 42) \tag{4}$$

Source: Carvalho Jr, E. C (2015) [5]

To calculate the population exposed to aeronautical noise, the method presented by Carvalho Jr. [5] was used, where the calculation is performed from the acoustic maps. The calculations of the exposed populations for the year 2015 and for the DNL metric were performed. From the QGIS software version 2.18, Excel platform, geometric data of the statistical subsections of the Census Sectors, in *shape format* (*shp*) and information for each statistical subsection (data from the 2010 IBGE Census), geometric data of the acoustic maps for the DNL acoustic indicator in *shape format* (*shp*), extraction of population data from the files, in format *shape* (*shp*), descriptive manual of the 2010 IBGE Census and database that were used for the calculation.

Using the QGIS software, the intersection of the data is performed to start the calculations, so the noise curves generated in the INM were superimposed on the IBGE census base layer, creating a new file. From the table of attributes of the file it was possible to identify the census codes indicative of the total number of residents per census tract. Then, with the indicator value DNL, the census code, and the total population calculated for each code, the calculation of the exposed population is performed.

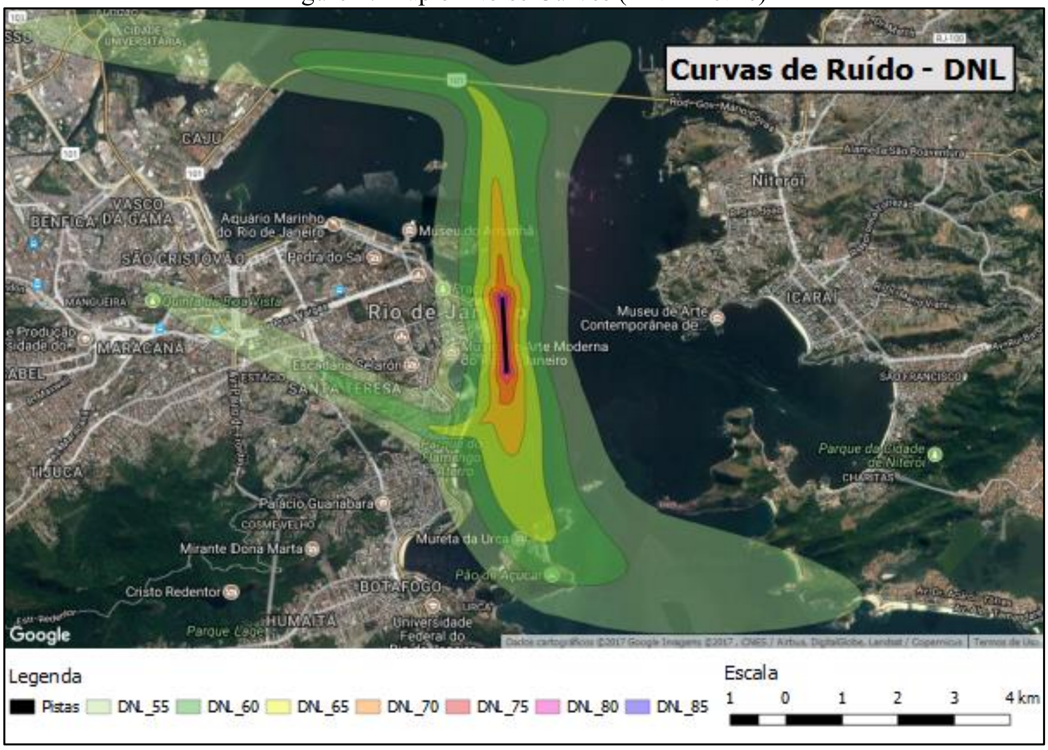
In order to avoid that the population data were overestimated in action of the intersection, which could assign equal values to areas between two or more noise curves, it was necessary to calculate the entire population of the comprehensive area of the largest noise curve and subtract from the results obtained from each curve. Thus, it was possible to obtain the overestimated percentage, since it was possible to identify the value calculated above the total.

4 RESULTS AND DISCUSSION

4.1 NOISE CURVES

After analysis of Santos Dumont's operation, the noise curves for the DNL metric were created. Figure 2 shows curves 55 through 85 (55 < DNL ≤ 85) for the year 2015. DNL 55 and 60 are presented for better analysis and quantification, but are not mandatory for RBAC 161/2013. In the interior of the curve DNL 60 it is possible to observe the population density, that although this curve is not necessary for the elaboration of the sound zoning, some researches show that the inhabitants of the interior of this curve feel highly bothered by the airway noise [1].

Figure 2: Map of Noise Curves (DNL Metric)



According to RBAC 161 [3], in the vicinity of the airport, the compatibility of land use must be made enabling the greatest use of area, preventing it from harming the performance of the aircraft or causing any damage to the parties involved in the process. DNL's 80 and 85 are delimited to the airport site, so they do not need to be included in the land use because they do not directly affect the community. Table 2 below presents the comparative summary of land use for the SBRJ.

Table 6: Comparative summary of land use for SBRJ

DNL	Permitted uses – RBAC nº 161/2013	Existing occupation	
		Compatible	**Incompatible**
55 and 60	Residential, public, commercial, industrial and recreational uses	All uses	No use
65	Residential[1], public[1],[2], commercial, industrial and recreational uses	Residences[1], temporary accommodation[1], recreational area, church[2]	No use
70	Residential[1], public[1,2], commercial[2], industrial[2] and recreational uses	Recreational area, naval school[1]	No use
75	Public[2], commercial[2] and industrial use[2]	No use	Naval Academy
80 and 85	Public use[2] and industrial[2]	No occupancy	No occupancy

1. With the authorization of the responsible bodies, adopting RR measures of at least 25 dB.
2. Compatible buildings, provided that they have an RR of 25, 30 or 35 dB when there is prolonged stay of people

Based on the intersection generated, from the method presented above, the attribute table available in QGIS was analyzed and the census codes of each DNL curve were identified. By joining the data from the file and the census spreadsheet, it was possible to determine the total population per neighborhood within these curves. From the generated file, the table of attributes was analyzed, being able to identify the census codes of each curve. Based on these data and the census spreadsheet, the total population (PTC) for each curve was determined, with a grand total of 76,502 people. Curves 75, 80 and 85 were not included in the calculation because they are inside the airport site, so they do not contain households and residents.

To determine the overestimated percentage, the value of the total population (76,502) was subtracted and the calculated value of DNL 55 (56,776), resulting in 19,726. Then, the division 19,726/76,502 was performed, the result was the overestimated percentage, of 25.78%. With this value, the exposed population (SP) was calculated in relation to the PTC. The values obtained are presented in Annex I. Thus, the neighborhoods most affected in DNL 55 were Glória and Cidade Nova. Already in DNL 60 we have Catete and Gloria. And in DNL 65, the most restrictive for land use according to RBAC 161, it was observed that the Flamengo and Urca neighborhoods have the same percentage of exposed population.

From equations 1, 2, 3 and 4, the percentages of bothered and highly bothered people were calculated. With the results obtained from the equations, and with the amount of population exposed, the percentage of bothered and highly disturbed people in each neighborhood was calculated, presented in Annex I, with the comparisons between the methods applied in Brazil and in the European Community. The comparison between the method used in Brazil and in the European Community showed that the results of the methodologies are close. The difference obtained between the two methods does not reach 4%, both in the percentage of bothered and highly bothered. It is found that the three neighborhoods with the highest percentages of exposed population are Glória, with 12.1%, Catete with 9.8% and Cidade Nova with 8.4%, and the Jurujuba and Maracanã neighborhoods with 0.1% are the least affected. Thus, the SBRJ does not have much impact on the residential areas in its surroundings, presenting only 0.1% of the population exposed in the neighborhoods of DNL 65, being the only one in which it presents occupation of residences.

5 CONCLUSION

The present study evaluated the environmental sound impact resulting from the operation of aircraft at Santos Dumont Airport in Rio de Janeiro. From the calculation of exposed population it was possible to identify that the percentages of people exposed in each noise curve are small in relation to the number of inhabitants per neighborhood. Finally, it is concluded that RBAC 161 (2013) can be complemented with the calculation of the exposed population along with the percentages of people who are disturbed and highly disturbed for a better evaluation of the impact of aeronautical noise in the areas surrounding the aerodromes. It is also recommended to include the PEZR in the Master Plan of Territorial Planning of the municipality and to promote a strict discipline of land use so that there is a good compatibility of the urban zoning with the sound zoning of the airport.

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ANEX 1.

Neighborhood	Pop	DNL 55							DNL 60							DNL 65						
		PTC	PE	%EP	Brazil		Europe		PTC	ON	%EP	Brazil		Europe		PTC	ON	%EP	Brazil		Europe	
					I%	AI%	I%	AI%				I%	AI%	I%	AI%				I%	AI%	I%	AI%
Bonsucesso	18.711	321	83	0,4%	25	11	24	9	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Caju	20.477	183	47	0,2%	14	6	14	5	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Catete	24.057	9.169	2.364	9,8%	711	319	690	260	5.362	1.382	5,7%	582	314	540	256	171	44	0,2%	24	16	22	12
Catumbi	12.556	2.346	605	4,8%	182	82	177	67	1.059	273	2,2%	115	62	107	51	-	-	-	-	-	-	-
Centro	41.142	2.324	599	1,5%	180	81	175	66	487	126	0,3%	53	28	49	23	38	10	0,02%	5	3	5	3
Charitas	8.121	143	37	0,5%	11	5	11	4	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Cidade Nova	5.466	1.783	460	8,4%	138	62	134	51	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Cidade Universitária	1.556	422	109	7,0%	33	15	32	12	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Estácio	17.189	2.719	701	4,1%	211	95	205	77	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Flamengo	50.043	8.982	2.316	4,6%	697	313	676	255	2.509	647	1,3%	272	147	253	120	1.457	376	0,8%	207	134	187	104
Glória	9.661	4.534	1.169	12,1%	352	158	341	129	1.410	363	3,8%	153	83	142	67	231	60	0,6%	33	21	30	16
Jardim Imbuí	1.127	227	59	5,2%	18	8	17	6	-	-		-	-	-	-	-	-	-	-	-	-	-
Jurujuba	2.797	10	3	0,1%	1	0	1	0	-	-		-	-	-	-	-	-	-	-	-	-	-
Maracanã	25.256	125	32	0,1%	10	4	9	4	-	-		-	-	-	-	-	-	-	-	-	-	-
Maré	129.770	8.518	2.196	1,7%	661	296	641	242	-	-		-	-	-	-	-	-	-	-	-	-	-
Praça da Bandeira	8.662	1.523	393	4,5%	118	53	115	43	-	-		-	-	-	-	-	-	-	-	-	-	-
Santa Teresa	40.926	9.434	2.432	5,9%	732	328	710	268	5.487	1.415	3,5%	596	321	553	262	-	-	-	-	-	-	-
Santo Cristo	12.330	612	158	1,3%	47	21	46	17	-	-	-	-	-	-	-	-	-	-	-	-	-	-
São Cristóvão	26.510	2.054	530	2,0%	159	71	155	58	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Urca	7.061	1.668	430	6,1%	129	58	126	47	1.284	331	4,7%	139	75	129	61	231	60	0,8%	33	21	30	16
TOTAL	**463.418**	**56.776**	**14720**	**3,2%**	**4431**	**1987**	**4298**	**1619**	**17.598**	**4537**	**1,0%**	**1910**	**1030**	**1774**	**839**	**2.128**	**489**	**0,1%**	**270**	**175**	**244**	**135**

Notes: Pop (Total population of each neighborhood. Source: População.net) / PTC = Total Calculated Population / PE = Exposed Population / %PE = Percentage of the exposed population in relation to the total population. / I% (Percentage of people bothered) / AI% (Percentage of people highly bothered)