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Flavio Maldonado Bentes*
Fundação Jorge Duprat Figueiredo de Segurança e Medicina do Trabalho
Rio de Janeiro/RJ – Brazil
flavio.bentes@ufrj.br

Jules Ghislain Slama
Instituto Alberto Luiz Coimbra de Pós-Graduação e Pesquisa em Engenharia
Rio de Janeiro/RJ – Brazil
jules@mecanica.ufrj.br

*author for correspondence

Sensitivity analysis of airport noise using computer simulation

Abstract: *This paper presents the method to analyze the sensitivity of airport noise using computer simulation with the aid of Integrated Noise Model 7.0. The technique serves to support the selection of alternatives to better control aircraft noise, since it helps identify which areas of the noise curves experienced greater variation from changes in aircraft movements at a particular airport.*

Keywords: *Sensitivity analysis, Airport noise, Computer simulation.*

LIST OF SYMBOLS

ANAC: National Civil Aviation Agency

SC_{xi}: Sensitivity cofficient of the movement variable

$SC_{xi'}$: Sensitivity coefficient of the movement variable without 10% of the aircrafts

dB: Decibel

dB(A): Decibel, according to the A ponderation curve

DNL: Day-night average noise level

$\Delta\Phi$: Variation in the area of the noise curve

FAA: Federal Aviation Administration

Φ: Area of the noise curve

INM: Integrated Noise Model

L_{Aeq}: Equivalent sound pressure level

L_{AeqD}: Day equivalent sound pressure level

L_{AeqN}: Night equivalent sound pressure level

RBAC: Brazilian Regulation for Civil Aviation

SEL: Sound exposure level

S_{xi}: Sensitivity to a movement x_i

SBRF: Guararapes International Airport (Recife/PE – Brazil)

x_i: Movement Variable for a group of aircrafts

INTRODUCTION

With the global growth of aerial navigation, airport authorities have become more concerned about issues related to aircraft noise. For Infraero (2010), to navigate means to safely conduct a watercraft or an aircraft from one point to another, which is a complex guidance process that enables long journeys with the goal to reach a specific place safely. The safety aspect should also include issues related to sound emission, once they can cause not only discomfort, but also damage to those who are continuously exposed to this type of noise. It is possible to say that the study of airport noise is really relevant worldwide, especially regarding issues related to aircraft noise. As to this aspect, the study concerning the sensitivity analysis is significantly helpful, since it allows identifying which areas of the noise curves have varied more from the changes in the aircraft movements at a specific airport.

Airport noise is usually a result of discreet events, such as landings and take-offs. There are different noise sources in airports, coming from land operations involving aircraft fueling, movements and maintenance, however, landing and take-off operations are considered as the main noise sources of an airport. According to Morais, Slama and Mansur (2008), airport noise is a result of a sound field with intermittent temporal characteristics. The noise coming from the aircraft movements is directly related to the procedures of the aircrafts on the ground, be it before take-off or after landing. The study concerning airport noise embraces different fields of knowledge, from physics to mechanical engineering, especially focusing on the acoustic phenomenon and issues concerning the environment.

The sensitivity analysis of airport noise is a method that uses acoustics software to simulate scenarios, with the objective to help control airport noise. Together with the guidelines of the balanced approach established by the International Civil Aviation Organization (2004), the technique contributes with a

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better analysis of the variations in the areas exposed to the levels of noise coming from the aircrafts. The numerical simulations use the Integrated Noise Model 7.0 (INM), which was created by the Federal Aviation Administration (2009) and enables the appearance of airport noise curves. INM requires the description of different airport parameters, such as runways, trajectories, fleet, route, airport coordinates, runway thresholds and noise curves starting from the choice of discomfort metrics.

METRICS FOR AIRPORT NOISE

There are different types of metrics to assess airport noise. Basically, noise metrics represents the energetic average of sound pressure levels in a definite period of time. According to the Brazilian Regulation for Civil Aviation 161 (2011), in order to determine noise curves, calculations should be made with software that uses appropriate methods with the day-night average level (DNL). This study presents a summary of some existing metrics: equivalent sound pressure level – L_{Aeq}, sound exposure level – SEL, and day-night average level – DNL).

Equivalent sound pressure level - L_{Aeq}

Noise levels can usually vary during a definite period of time. For Gerges (2000), the damaging effects of noise depend not only on its level, but also on how long it lasts. It is possible to say that L_{Aeq} is a constant sound pressure level that is equal to the variable noise levels during the measuring period, in terms of acoustic energy. As a consequence, L_{Aeq} represents the average sound level resulting from the integration throughout a period of time that can be defined with the logarithmic sum of all sound levels. L_{Aeq} can be divided between day and night. L_{AeqD} is the day equivalent sound pressure level and represents the average sound energy calculated during daytime, from 7 to 22h, with a total of 15 hours. L_{AeqD} is determined by Eq. 1.

$$L_{AeqD} = 10 log \left[\frac{1}{54000} \int_{7}^{22} 10^{\frac{LA(t)}{10}(t)} \, dt \right] \quad (1)$$

L_{AeqN} is the night equivalent sound pressure level, and represents the average sound energy calculated during the night, from 22h to 7h, with a total of 9 hours. L_{AeqN} is determined by Eq. 2.

$$L_{AeqN} = 10 log \left[\frac{1}{32400} \int_{22}^{7} 10^{\frac{LA(t)}{10}(t)} \, dt \right] \quad (2)$$

Sound exposure level – SEL

SEL represents the total noise energy produced from an event. It is possible to say that *SEL* represents a logarithmic expression of the acoustic energy of the event, once it exceeds a specific type of noise, as if it had happened within a second. Thus, *SEL* is obtained by the sum of all sound pressure levels in one unit of time, inside the analyzed interval. Since *SEL* is a logarithmic expression regarding sound exposure in time, it can be used to compare the noise energy of events that last for different periods. The mathematical formulation to express the definition of *SEL* is demonstrated in Eq. 3:

$$SEL = 10 log \left[\frac{1}{T_0} \int_{t}^{t+T} \frac{P_A^2}{P_0^2}(t) \, dt \right] \quad (3)$$

Day-Night Average Sound Level – DNL

DNL is commonly used to define the level of exposure to airport noise, and it also corresponds to the average sound energy caused by all airport events in a period of 24 hours. Ten dB (A) are added to the noise level for sound levels that occur during the night, from 22h to 7h of the next day, due to the higher sensitivity and disturbances caused by noise at night. According to the Code of Federal Regulations 14 CFR 150 (2004), *DNL* combines the sound energy of all aircraft operations from events that occur during daytime at an average noise exposure for that day. It is possible to say that the calculation of *DNL* is similar to L_{Aeq}, except that DNL adds 10 dB (A) to the night sound and is calculated in a period of 24 hours. According to Bistafa (2006), the relation between them is obtained with L_{Aeq} of every hour of each day. The average energy sum of the day and night, with extra 10 dB (A), results in the *DNL*. Eq. 4 mathematically defines DNL.

$$DNL = 10 log \left\{ \frac{1}{3600.24} \left[\int_{7}^{22} 10^{\frac{LA(t)}{10}} \, dt + \int_{22}^{7} 10^{\frac{LA(t)+10}{10}} \, dt \right] \right\} \quad (4)$$

DNL is usually used to define the areas of the noise curve, and has functions such as quantifying the cumulative noise exposure, considering events taking place during the day and the night. In Brazil, because of a recommendation by RBAC 161 (2011), *DNL* is used to calculate airport noise curves. The Code of Federal Regulations 14 CFR 150 (2004) also emphasizes that DNL has a penalty for night events since they cause more discomfort. We can say that DNL will identify the events that cause higher noise levels.

METHODS AND DATA

With the use of INM 7.0, the variations of the area of the noise curve ($\Delta\phi$) will be studied with *DNL*, as established by RBAC 161 (2011), in relation with variations of airport movements. The values of sensitivity coefficients are calculated after the elaboration of noise curves with INM, over the individual variation of each parameter, with other fixed parameters. Thus, it is possible to say that $\phi = (x_1, x_2, ..., x_n)$, in which the variable x_n corresponds to the aircraft movements, during the daytime or the night. Considering the ϕ variation when $x_1, x_2, ..., x_n$ varies to $x_1 + \Delta x_1, x_2 + \Delta x_2, \ldots, x_n + \Delta x_n$, as demonstrated in Eq. 5:

$$\Delta\phi(x_1, x_2, ..., x_n) = \phi(x_1 + \Delta x_1, x_2 + \Delta x_2, ..., x_n + \Delta x_n) - \phi(x_1, x_2, ..., x_n) \quad (5)$$

Thus, $\Delta\phi$ can be described as demonstrated in Eq. 6:

$$\Delta\phi(x_1, x_2, ..., x_n) = \frac{\partial\phi}{\partial x_1}\Delta x_1 + \frac{\partial\phi}{\partial x_2}\Delta x_2 + ... + \frac{\partial\phi}{\partial x_2}\Delta x_n \quad (6)$$

Therefore, it is possible to obtain the relative variation, which is equivalent to Eq. 7:

$$\frac{\Delta\phi(x_1, x_2, ..., x_n)}{\phi(x_1, x_2, ..., x_n)} = \frac{x_1}{\phi(x_1, x_2, ..., x_n)} \frac{\partial\phi}{\partial x_1} \frac{\Delta x_1}{x_1} + \cdots + \frac{x_n}{\phi(x_1, x_2, ..., x_n)} \frac{\partial\phi}{\partial x_n} \frac{\Delta x_n}{x_n} \quad (7)$$

The x_i motion sensitivity can be defined by Eq. 8:

$$S_{xi} = \frac{x_i}{\phi(x_1, x_2, ..., x_n)} \frac{\partial\phi}{\partial x_1} \quad (8)$$

Replacing Eq. 8 in Eq. 7, we come to Eq. 9:

$$\frac{\Delta\phi(x_1, x_2, ..., x_n)}{\phi(x_1, x_2, ..., x_n)} = S_{x1}\frac{\Delta x_1}{x_1} + S_{x2}\frac{\Delta x_2}{x_2} + \cdots + S_{xn}\frac{\Delta x_n}{x_n} \quad (9)$$

The values of sensitivity coefficients are defined from the determination of areas of noise curve using INM for the variation of each x_i movement. Thus, ϕ values were determined for $x_1, x_2, x_3, (...), x_n$ in the initial situation and after the parameter variation for $x_1 + \Delta x_1, x_2 + \Delta x_2, x_3 + \Delta x_3, (...), x_n + \Delta x_n$. Therefore, the sensitivity coefficient for x_i will be demonstrated in Eq. 10:

$$CS_{xi} \approx \frac{x_i}{\phi} \frac{\Delta\phi}{\Delta x_i} \quad (10)$$

The sensitivity coefficients can be expressed for x_1 movements (group A, daytime), x_2 (group A, night), x_3 (group B, daytime), and x_4 (group B, night). Equation 11 represents the sensitivity coefficient for a determinate x_i movement:

$$CS_{xi} \approx -10 \frac{\phi_i - \phi_0}{\phi_0} \quad (11)$$

Considering a logarithmic relation, it is possible to relate the logarithm of the area of the noise curve and the logarithm in relation to the movements multiplied by their respective sensitivity coefficients, which will result in Eq. 12:

$$log_e\phi(x_1, x_2, ..., x_n) = CS_{x1} log_e x_1 + CS_{x2} log_e x_2 + ... + CS_{xn} log_e x_n + cte \quad (12)$$

The sensitivity analysis was conducted with computational numerical analysis in Guararapes International Airport – Recife/PE, Brazil (SBRF). Information concerning the flights was gathered via online airline schedule provided by the National Civil Aviation Agency (ANAC), from Brazil (2011). Table 1 presents aircraft movements by period.

RESULTS

The areas of noise curves were calculated for all the aircrafts. Afterwards, the areas of noise curves in groups A and B were calculated both for daytime (D) and night (N)

Table 1.Aircraft movements by period.

Movements	Period	Aircrafts	Group
x_1	D	A318, A319, A320, A321, A332, A343, B733, B734, B737, B738, B744, B752, B762, B763, E190, F100	A
x_2	N	A318, A319, A320, A321, A332, A343, B733, B734, B737, B738, B744, B752, B762, B763, E190, F100	A
x_3	D	AT72, B722, L410	B
x_4	N	AT72, B722, L410	B

movements. Table 2 presents the values of areas of noise curves calculated for the respective groups of aircrafts. Calculation was conducted with *DNL*, as recommended by RBAC 161 (2011), for different noise curves, and the object of analysis was Guararapes International Airport – Recife/PE, Brazil (SBRF).

Table 3 presents the values of areas of noise curves calculated after 10% of the aircrafts had been removed for all movements. Simulations were conducted with the same metrics, resulting in DNL 55, 60, 65, 70, 75, 80 and 85 dB(A) noise curves, with their respective characteristics.

Table 4 presents the sensitivity coefficient values before (SC_{xi}) and after ($CS_{xi'}$) 10% of the aircrafts were removed. Sensitivity variations are more noticeable for bigger changes in noise curve areas, which were calculated and are demonstrated in Tables 2 and 3.

From the analysis conducted after obtaining the sensitivity coefficients, it is possible to imply there will be a higher variation in the noise curve areas for the movement variables x_3, x_4 (Table 2) and $x_{3'}$, $x_{4'}$ (Table 3). The higher the variation of the area of noise curves, the bigger the reduction of the noise, since the area of the noise curve will decrease. For movements x_1, x_2, $x_{1'}$, $x_{2'}$, especially x_2, $x_{2'}$, lower values of sensitivity coefficients were calculated in almost all the curves, which shows a lower variation as to noise curves for the respective movements and the maintenance of higher noise levels, close to the initial condition.

Table 2. Values of noise curve areas with all the aircrafts.

DNL (dB(A))	Noise curve areas with all the aircrafts (km²)				
	All the aircrafts	Group A Daytime (x_1)	Group A Night (x_2)	Group B Daytime (x_3)	Group B Night (x_4)
55	47,609	11,382	30,998	3,875	1,778
60	19,034	4,359	11,753	1,326	0.527
65	7,030	1,684	4,582	0.338	0.111
70	2,569	0.589	1,756	0.102	0.045
75	1,022	0.161	0.689	0.023	0.014
80	0.25	0.065	0.173	0	0.001
85	0.1	0.013	0.073	0	0

Table 3. Values of noise curve areas after 10% of the aircrafts were removed.

DNL (dB(A))	Noise curve areas after 10% of the aircrafts were removed (km²)				
	All the aircrafts	Group A Daytime ($x_{1'}$)	Group A Night ($x_{2'}$)	Group B Daytime ($x_{3'}$)	Group B Night ($x_{4'}$)
55	38,983	10,513	28,028	3,685	1,617
60	14,266	4,166	10,699	1,289	0.556
65	5,645	1,581	4,313	0.479	0.214
70	2,025	0.579	1,648	0.165	0.087
75	0.838	0.231	0.653	0.045	0.028
80	0.197	0.086	0.258	0.008	0.005
85	0.085	0.023	0.095	0.001	0

Table 4. Values of sensitivity coefficients for different noise curves before and after the aircrafts were removed.

DNL (dB(A))	SC_{xi} values				$SC_{xi'}$ values			
	SC_{x1}	SC_{x2}	SC_{x3}	SC_{x4}	$SC_{x1'}$	$SC_{x2'}$	$SC_{x3'}$	$SC_{x4'}$
55	7,609	3,489	9,18608	9,62654	7,303	2,810	9,05472	9,58520
60	7,710	3,825	9,30335	9,99972	7,080	2,500	9,09645	9,99961
65	7,605	3,482	9,99952	9,99984	7,199	2,360	9,99915	9,99962
70	9,998	3,165	9,99960	9,99982	9,997	1,862	9,99919	9,99957
75	9,998	9,993	9,99977	9,99986	7,243	2,208	9,46301	9,66587
80	7,400	3,080	10,00000	9,96000	5,635	3,096	9,59391	9,74619
85	8,700	2,700	10,00000	10,00000	7,294	1,176	9,88235	10,00000

CONCLUSIONS

Using the sensitivity analysis by computational numerical simulation enables to identify the variations in the most significant areas of noise curves that should be carefully analyzed by airport authorities. Since the subject of airport noise is really relevant in the international context and due to the expectations as to the growth of the aerial modal, the study of sensitivity analysis can be seen as a tool to help noise control, especially since it enables identifying which areas of noise curve vary the most. Thus, its use makes measurements to control airport noise more effective.

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