

Aircraft Noise Evaluation: First Stage*

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Abstract. This paper presents the characteristics of aircraft noise and a brief description of some of its effects in human beings. The method uses frequency and octave analysis as well as indicators' calculation; programmed by virtual instruments. The obtained results show that the most significant frequencies are the low ones (around 100 Hz), and some of the effects caused by the noise are stress and sleeping problems.

1 Introduction

Nowadays noise has become a serious problem in all the big cities of the World. It is caused by a great variety of electronic machines, factories, etc. However, one of the more bothering noises that can be found is the one generated by means of transport. Among these, airplanes generate the biggest amount of acoustic energy; therefore, the closest areas to the airports are the most affected.

If the noise level generated by planes has been decreasing with the pass of time due to new technologies, it is also true that recent studies relate this kind of noise with annoyances to human beings, for example, difficulties when communicating, sleeping problems, etc. All this leads us to think about: How is the aircrafts' noise? Which characteristics does it have? Etc.

The purpose of this paper is to analyze the characteristics of aircrafts' noise; to make a comparison between aircrafts with propellers and jet aircrafts and to show brief some of the most common effects of these events.

It also important to mention that the sound patterns used to the elaboration of this research, were taken from the International Airport of Mexico City (AICM) during the takeoffs of the aircrafts. The takeoffs' sound was taken as reference because it is when the highest level of noise is produced; hence the bigger troubles for the nearby community.

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2 Data acquiring

2.1 Measurement tools

The used aircrafts' noises in this work have been acquired by means of MP201 microphone. It is a good choice for use in IEC61672 class 1 sound level meters and other noise measurements requiring class 1 accuracy [1]. It is a 1/2" prepolarized free-field measurement microphone. The data acquisition card is USB-9233. It is a four-channel dynamic signal acquisition module for making high-accuracy measurements from IEPE sensors. The USB-9233 delivers 102 dB of dynamic range. The four USB-9233 input channels simultaneously acquire at rates from 2 to 50 kHz. In addition, the module includes built-in antialiasing filters that automatically adjust to your sampling rate. The USB-9233 uses a method of A/D conversion known as deltasigma modulation. If the data rate is 25 kS/s, each ADC actually samples its input signal at 3.2 MS/s (128 times the data rate) and produces samples that are applied to a digital filter. This filter then expands the data to 24 bits, rejects signal components greater than 12.5 kHz (the Nyquist frequency), and then digitally resample the data at the chosen data rate of 25 kS/s. This combination of analog and digital filtering provides an accurate representation of desirable signals while rejecting out-of-band signals. The built-in filters automatically adjust themselves to discriminate between signals based on the frequency range, or bandwidth, of the signal.

2.2 Measurement characteristics

In this paper, the noise samples were acquired with sampling frequencies of 25000 Hz (Samples/second: S/s), monophonic and during 24 seconds. In general, this interval is greater than the aircraft takeoff time, or greater than the time in which the produced noise affects the zones near an airport. The takeoff direction is always the same one and this reduces the disturbances of Doppler Effect.

According to [2], three points of reference must be taken in count to make measurements of airplanes' noises. The first one is a lateral point at 450m (it can vary depending on the airplane that will be measured); the second is located at 6.5 Km. in straight line from the start of the takeoff path: the last one is placed at 2 Km. before the runway in order to measure the approximation noise.

Something that has to be noticed in the AICM is that at 130m from one side of the runway, there are houses. That is why it was decided to measure at this point to observe the noise level present in this homes and also because in takeoffs, the lateral point is the most significant.

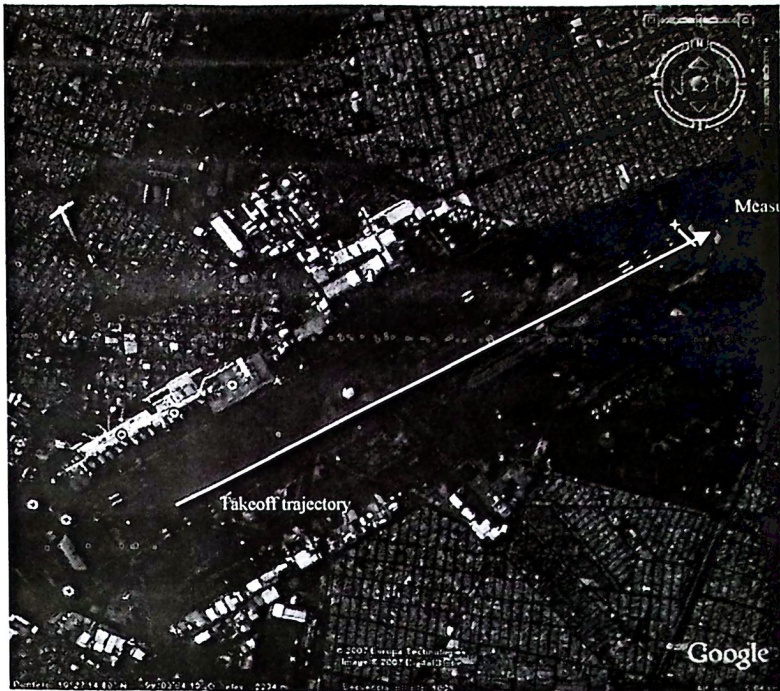


Fig 1 Map of AICM

The measurement point is placed at approximately 130m in a perpendicular way to the runway and is located at $19^{\circ}26'41''$ N, $99^{\circ}3'44''$ W. The meteorological conditions at the moment of the measurement were: temperature 19° Celsius and relative humidity of 64 %.

3. Data Processing

In order to obtain valuable information from the gathered information, it is necessary to process it. This can be done in several ways, one of them is to get statistic indicators which are used to discover the urban noise [3][4]; another way is to make a frequency analysis. This analysis allows us to get the spectral characteristics of the signal. Finally, the last option is to use an octave analysis, the information gotten from this analysis is the energy contained in each one of the frequency bands.

3.1 Sound Indicators [3][4][5]

There is a huge variety of indicators. However, the indicators used for monitoring aircraft's noise are: instant sound level (L_p), highest sound level (L_{max}), the perceived noise level (PNL), the sound exposure level (SEL), the effective perceived noise level (EPNL), the equivalent sound level (Leq), the day/night sound level (DNL), the community noise equivalent level (CNEL), and the level of exceeded sound in a percentile x (L_x).

Most of these indicators require long term measurements, some of them even of 24 hours. They refer to the way the sound behaves through time; during measurement, a lot of information is collected from a wide variety of aircrafts; therefore, we cannot obtain the individual behavior of each one of them. Some other indicators are subjective values that may not reflect the characteristics of aircrafts' noise.

The selected indicators let us get information about the energy generated by aircrafts' noise in an individual way. They can be obtained from measurements of 24 seconds. The indicators used are the following:

- Equivalent sound level (Leq). It is the sound level that would have a constant noise in the same period of time than the measured noise. The Leq represents the sound energy contained in noise in a determined time.

$$Leq = 10 \cdot \log \left[\frac{1}{T} \cdot \int_0^T \frac{P^2(t)}{P_0^2} dt \right] \quad (dB), \quad (1)$$

- Sound exposure level (SEL). It is the sound level that if kept constant during 1 second, would have the same energy that the measured sound event. It is used to measure isolated events such as the passing of airplanes, etc.

$$SEL = 10 \cdot \log \left[\int_{t_1}^{t_2} \frac{1}{T_{ref}} \cdot 10^{\frac{L_p(t)}{10}} dt \right] \quad (dB), \quad (2)$$

- Maximum sound level (L_{max}). It is the highest sound level that is registered during a period of time.
- L10, L50, L90. It is the sound level that is surpassed and is determined by a time percentage. For example, the L90 is the sound level that was surpassed during 90% of the measurement time.

Table 1. Indicators for the MD87 shown in Fig 2.

Indicator	Value
Leq	95.25 dB
SEL	109.056 dB
Lmax	114.79 dB
L ₁₀	98.9744 dB
L ₅₀	84.9091 dB
L ₉₀	68.3066 dB

3.2 Frequencies Analysis

Frequencies analysis is one of the most used techniques for signal analysis. In this case, having discrete values, it is obtained by the FFT (Fast Fourier Transform). This lets us get the spectral components of the analyzed noise.

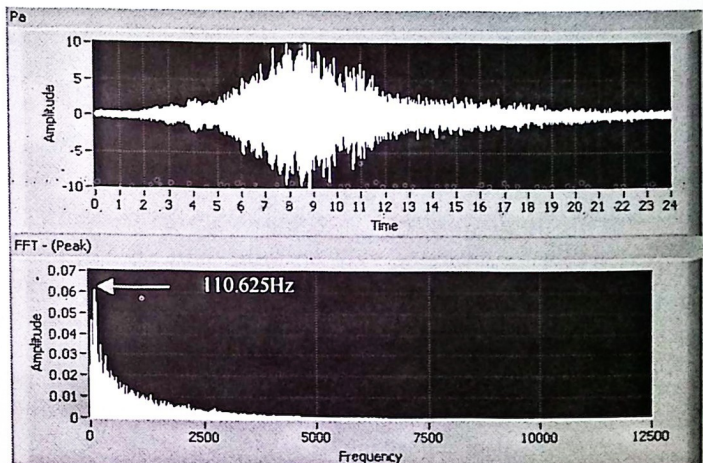


Fig 2 Noise of MD87 aircraft taking off, with sampling frequency of 25000 Hz.

As it can be seen in Fig 2, the noise produced by the plane MD87 during the takeoff reaches levels close to 10 Pa. In addition, the overtones of greater amplitude are contained between 30 and 210 Hz. (Counting the components that have at least half of the maximum amplitude), having the maximum value in 110.625 Hz.

3.3 Frequency weighting filters

The human ear is not equally sensitive to sound at different frequencies. To adequately evaluate human exposure to noise, the sound measuring system must account for this difference in sensitivities over the audible range. For this purpose, frequency weighting networks, which are really “frequency weighting filters”, have been developed [6].

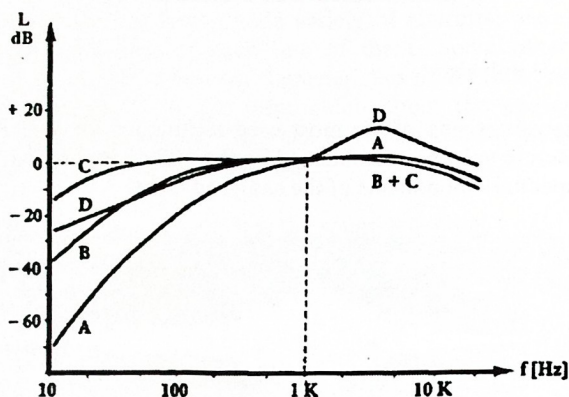


Fig 3 Frequency weighting filters

There is a large variety of frequency weighting filters; they evaluate different types of noise. There is also the frequency weighting filter D, which was developed to characterize the effects of aircrafts' noise. However, the two internationally standardized weighting networks in common use are the “A” and “C”, which have been built to correlate to the frequency response of the human ear for different sound levels. Their characteristics are defined in [7].

- Frequency weighting filter A. It was created to model the human ear response to low intensities. Nowadays, almost all the laws and rules use it to limit the acceptable noise levels. The weighted A sound levels are called decibel A dB(A). The values of the frequency weighting filter A can be calculated basing on the next formula. [7]:

$$A(f) = 20 \log \left(\frac{1,2588 \times 12200^2 f^4}{(f^2 + 20,6^2) \sqrt{f^2 + 107,7^2} \sqrt{f^2 + 737,9^2} (f^2 + 12200^2)} \right) \quad (3)$$

- Frequency weighting filter C. It was created to model the human ear response to great intensity sounds. It is used to evaluate ambient and low

frequency sounds in the band of audible frequencies. The values of the frequency weighting filter C can be calculated basing on the next formula [7]:

$$C(f) = 20 \log \left(\frac{1,0071 \times 12200 f^2}{(f^2 + 20,6^2)(f^2 + 12200^2)} \right) \quad (4)$$

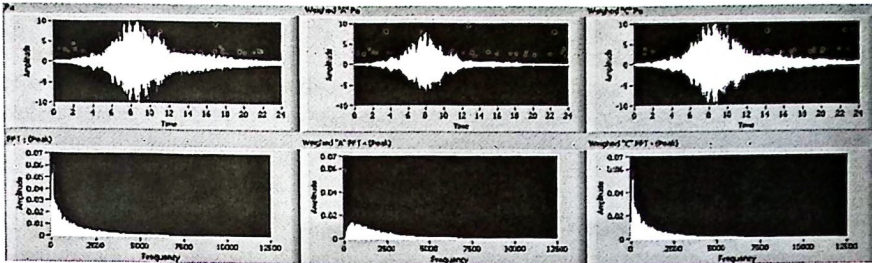


Fig 4. Left: Original Signal; Center: Weighted “A” Signal; Right: Weighted “C” Signal.

On Fig. 4 we can see that when the frequency weighting filter A is applied, it annuls the low frequencies, which in the case of aircrafts’ noise are quite significant.

When weighting, the later calculations are affected, this can be seen in the sound indicators. This is really important because in many places the permitted limits of noise are defined in dB(A) because it is the way the ear responses. However, the noise not only affects the ear, but all the body, and it responses to the frequencies in a different way than the ear.

3.4 Octave Bands Analysis

The human auditory mechanism is more sensitive to proportions of frequencies than to frequencies. The frequency of a sound will determine its height as perceived by a hearer; a proportion of two times a frequency is heard as a change of height of an octave, no matter which were the frequencies. If for example, a sound goes up from 100 Hz to 200 Hz, its height will increase in one octave; when a 1000 Hz sound goes up to 2000 Hz, it will also increase in one octave of height. This fact is valid with so much precision in an important frequency range, that it is convenient to define an octave as a proportion of frequencies of two, although the octave itself is a subjective measure of change of height in a sound.

For the ear, an octave is an interval of frequencies. The octave analysis is defined as a rule for the acoustic analysis. In this case, the third of octave analysis was used to get a better resolution.

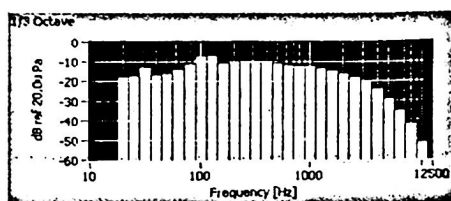


Fig 5 Noise produced by a MD87 in a third of octave analysis.

4. Comparison between propeller aircraft and jet aircraft

These days, there are mainly two types of aircrafts: with propellers and jets. The propeller aircrafts were the first ones to be used. However, the jets can carry more weight and therefore can transport bigger airplanes. The only problem they have is that they generate a lot more noise than propeller aircrafts, as can be seen in the following figure.

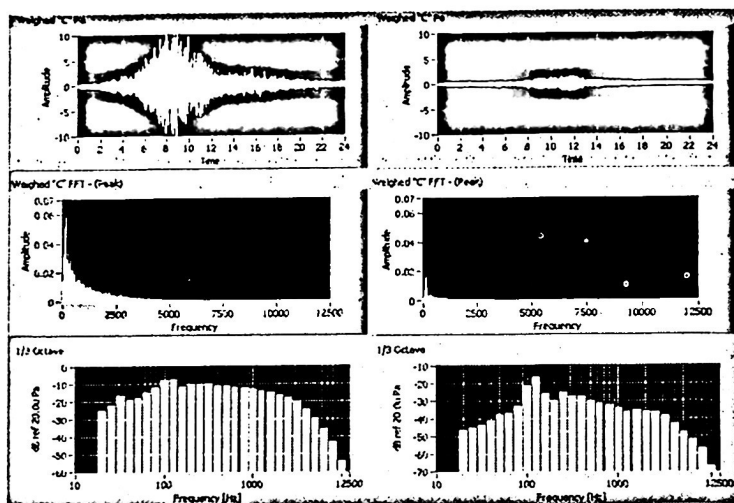


Fig. 6 Left: Noise of a MD87 (jet); Right: Noise of an ATR-42 (propellers).

The information shown in Fig. 6 was acquired by using a frequency weighting filter "C". In spite of all the differences between both airplanes, it can be seen that the amplitude of the overtones in both cases is bigger when it is near to 100 Hz.

Table 2. Comparison between noise indicators.

Indicator	MD87		ATR-42	
	dB(A)	dB(C)	dB(A)	dB(C)
Leq	89.86	94.87	71.24	80.24
SEL	103.659	108.671	85.0437	94.0436
Lmax	111.86	114.78	93.01	97.33
L ₁₀	93.0506	98.5465	74.9248	84.2573
L ₅₀	74.1949	83.7636	63.0512	70.0208
L ₉₀	56.1661	67.1381	47.7169	54.6854

Although these a priori values do not cross the established limits, it is also interesting that the norm specifies that the lateral measurements have to be made between 450 and 650m, and in this zone, the closest houses are at 130 perpendicular meters from the runway, causing annoying problems to the habitants of this area.

5. Noise effects on humans.

We can find the following effects on humans of the frequencies contained inside the aircrafts' noise.

Table 3. Effects of the noise.

Effect	Causing frequencies	Sound pressure level	Exposition time.
A little pain in the ear [8][9]	50 - 8000 Hz	110 dB	Seconds
Interferences in communication [4][9]	30 - 100 Hz	> 90 dB	Minutes
	100 - 4000 Hz	> 50 dB	
Body vibrations [10]	4 - 100 HZ	>105 dB	Seconds
Stress [8]	The whole spectrum	>105 dB	Minutes

Stress may have different physical or psychological manifestations. Some examples of this may be allergies, hives, back pain, muscular cramps, asthma, bronchitis, high pressure, migraine, duodenal ulcer, colitis, obesity, anxiety, fatigue, etc. [11].

Other effects of noise have been detected although there is not information as specific as the exposed on Table 3. Some of these are:

- Sleeping problems [12][13]
- Hypertension [11] [13]

Almost all of these problems are still objects of study.

Even during the measurements that lasted approximately 3 hours, some effects such as headaches, ears buzzing, and fatigue, were felt. These effects continued after hours of finishing with measurements.

6. Conclusions and Future Work.

The most significant frequencies in planes are the low ones (around 100 Hz). As a preliminary way, it can be said that frequency weighting filter "A", is not completely useful to measure airplanes' noise because it annuls low frequencies; although these frequencies cannot be detected by the human ear, the body responses to them in other ways such as stress. Considering that most of the legislations use frequency weighting filter "A" to establish the maximum noise levels, it is possible that all the noise effects are not considered because of the annulled frequencies.

For the future work, it is advisable to analyze the convenience of decreasing the spectral resolution in order to eliminate the noise of the patterns. Other indicators must be used; it can be the case of the EPNL, and other similar indicators. It is highly convenient to research more about noise's effects on health, specially the one generated by airplanes.

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