Aircraft cabin noise synthesis for noise subjective analysis

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Abstract. *On the early design phases of an aircraft, confort and ergonomy aspects are frequently evaluated with the usage of real size cabin mock-ups. The interior of this mockup should be as representative as possible of the real aircraft interior. For that, it is necessary to simulate real aircraft ambiental conditions inside the mockup. These ambient conditions include: air temperature and circulation characteristics, pressure, vibration and nois. This work aims to develop a system to control the amplitude and frequency characteristics of noise presented in an ambient, taking them to pre-defined targets. LabVIEW programming environment will be used to synthesize signals that, when input to an amplifier-loudspeaker system, will reach these pre-defined targets. Commercial soundcards will be used for signal generation and LabVIEW to acquisition.*

Keywords*: aircraft design, aircraft cabin noise, LabVIEW*

1. INTRODUCTION

When a new aircraft design is proposed, real-size mockups of the proposed aircraft are often used for the evaluation of several design items, such as: space availability for systems, passenger comfort and ergonomics, overall operability of the aircraft, emergency escapes evaluation. They are also used on sales campaigns of the new aircraft, to introduce it to potential customers. The main idea is often to produce a full sized replica, using inexpensive materials in order to verify physical aspects relative to aircraft composition.

Figure 1 shows an example of aircraft mockup.

Figure 1 - (a) Aircraft mockup and (b) Mockup detail

Human subjective comfort evaluations are also performed inside mockups. In this case it is highly desirable that the environmental conditions inside the mockup are as close as possible to the conditions occurring in a real operation, so that the subjective responses obtained with these evaluations can be extrapolated to normal situations. Such environmental conditions include: vibration and noise levels, air temperature and pressure, between others. This work focus in the acoustic environment inside the mockup. A simple system was developed to reproduce desired noise signatures inside a generic mockup. The system allows the control of the noise characteristics, thus allowing the evaluation of subjective human responses to different noise features. In the case of the present work, noise characteristics of a real aircraft in normal operation were used to exemplify the software usage.

2. BACKGROUND AND METODOLOGY

Typically, noise evaluation tests are performed with the test subjects using headphones playing the noise to be evaluated. The main advantage of this approach is that there is a very good control on the sound that is actually being listened by the subject, because environmental influences on the noise propagation are minimized. However, the simple fact that the person is subjected to wear headphones can highly influence the subjective perception of the ambient noise, and also jeopardize an accurate reproduction of a general aircraft environment.

The approach used on this work proposes the creation of the noise environment of the mockup with the usage of speakers placed behind the mockup walls. With that a continuous noise characteristic can be introduced on the whole mockup cabin, which is more representative of a real aircraft operation.

However, the execution of this approach has a clear difficulty, which is how to guarantee that the desired noise characteristic to be evaluated is arriving at the subjects. This difficulty arises from the complicated transfer function existing between noise generation and noise perception by the listener: the speaker system will present a frequency response which will distort the signal, the whole mockup itself will greatly modify the sound due to reflections and absorptions on its surfaces. Even the speaker generated sounds will interfere with each other. Due to the high number of variables this transfer function cannot be accurately defined.

Modern approaches to the solution of these problem use active control systems to reproduce a desired acoustic pressure field inside an ambient. More details on this approach can be found on REF 1.

The present work approach is to manually adjust the system noise input, aiming to minimize the difference between measured ambient noise and a predefined noise target, which can be a real aircraft cabin noise measured at a real operation. The system transfer function will be corrected by these adjustments inserted on the input signal. Despite the simplicity of this approach, its cost/benefit relation can justify its usage in several practical situations.

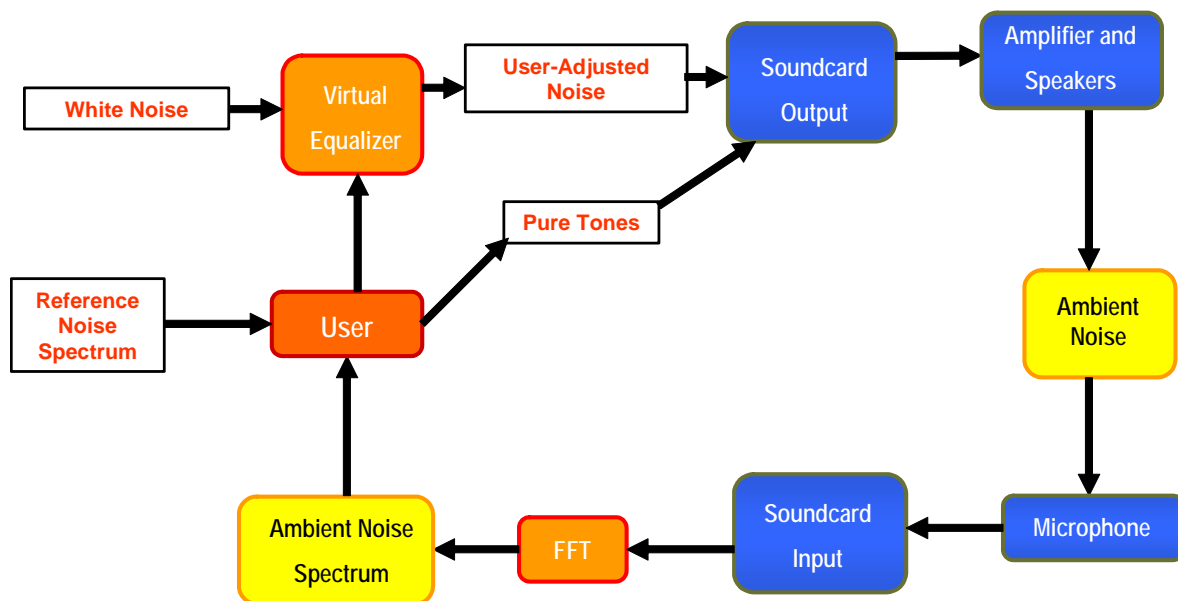The block diagram in figure 2 depicts the system functioning:

Figure 2 – System Block Diagram

Fig. 2 diagram shows that the process starts with the generation of a white noise signal, which has its energy equally distributed over all the frequency range. By means of a Virtual Equalizer, the frequency composition of the white noise is altered, that is, the frequency composition of the noise can be attenuated or improved. Pure tones are also generated and added to the final output signal, which is then sent to the soundcard output port. After proper amplification the signal is sent to speakers, which translate it into ambient noise. Due to environmental influences mentioned before, the ambient noise yielded is very different from the signal output from the soundcard. This ambient noise is captured by a microphone, whose signal is fed into the input port of the soundcard. A Fast Fourier Transform is then applied to the measured noise signal. From that the spectra of ambient noise can be evaluated. Finally, the software user analyzes the ambient noise spectra through the user interface, compares it with a predefined target noise (which can be a real aircraft measured noise), and performs the necessary adjustments on the input noise signal, in order to take the ambient noise as close as possible to the desired reference spectrum.

In order to integrate and execute all tasks mentioned in the early diagram, a graphical programming environment development by National Instruments was used: the LabVIEW software (LabVIEW, 2003). This is a

general-purpose programming system whose programs are built in a block diagram form. LabVIEW program contains an extensive library of functions for data acquisition, instrument control, measurement analysis and report generation applications. LabVIEW-generated software are also referred to as virtual instruments, which means that the operations and appearance of the software can imitate actual instruments.

Virtual instruments are structured as follows:

1. The control or user interface of virtual instruments is known as the front panel. The front panel simulates the panel of a physical instrument.
2. Instructions that are given to the virtual instrument are in the form of a block diagram.
3. Virtual instruments can be used as a "top-level program", or as a subprogram of another program.

- **Front Panel**

The "user interface" of VI looks like that of an instrument. An example is shown in Figure 3. This "user interface" is known as the front panel.

- **Block Diagram**

With the block diagram, you can construct a block diagram that wires together objects that send or receive data, perform specific functions, and control the flow of execution.

- **Icon and Connector**

An icon is either the pictorial or the textual representation of the purpose of the Virtual Instrument, or its terminals. A connector is a set of terminals that correspond to the sub Virtual Instrument controls and indicators.

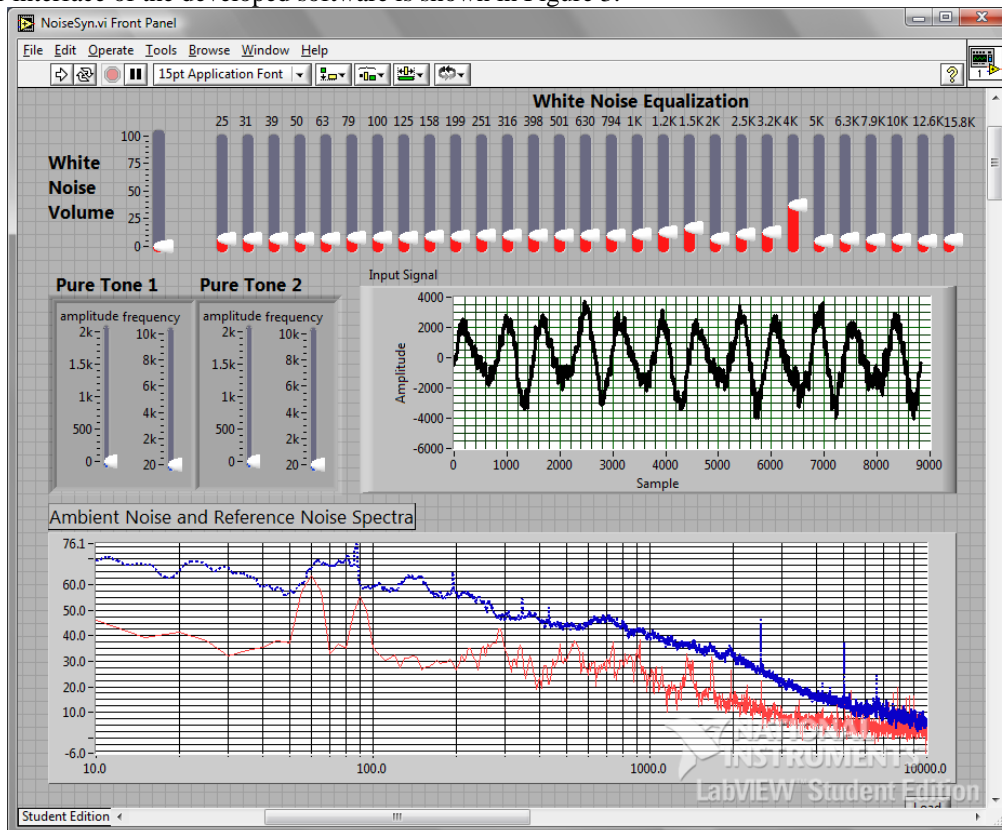The user interface of the developed software is shown in Figure 3.

Figure 3 – User interface of the developed software

The controls included in the user interface are:

1 – White noise volume – this slidebar enables the user to control the amplitude of the white noise generated by the software.

2 – White noise equalization – after the definition of the amplitude of the white noise, the relative influence of each frequency band on the output signal can be regulated by means of a 29 band virtual equalizer.

3 – Pure Tones – for best flexibility in terms of generated noise characteristics, the user is also allowed to add 2 pure tones to the generated noise, with the definition of the amplitudes and frequencies of these tones.

4 – Input Signal – this graph shows in real time the signal currently being measured by the microphone connected to the input of the soundcard.

5 – Ambient Noise and Reference Noise spectra – this graph shows the reference noise spectrum chosen by the user (dotted blue line) in comparison with the ambient noise spectrum measured by the microphone. This graph is updated in

real time, and thus responds to changes in microphone input signal. The difference observed between the measured and reference spectrum will guide the user to perform the necessary changes in input signal, in order to make both spectra match.

3. IMPLEMENTATION

As early mentioned the software-based operations involved on the system were developed at the LabVIEW programming environment. The main functions used by the software are depicted as follows:

- Soundcard interface was performed with the aid of WaveIO [1] soundcard interface for LabVIEW. This interface uses standard Windows APIs to make the connection between LabVIEW and the soundcard. It means that all the sound devices currently installed on the computer are readily made available for signal input and output.
- Broadband noise generation was performed with the Uniform White Noise Waveform. vi.
- A 29-band virtual equalizer was implemented with Chebyshev filters of 5th order, with the usage of the "Filter" block available at LabVIEW. The filters were centered at the 1/3 octave bands center frequencies from 25 Hz to 16kHz. This comprises the whole audible frequency range.
- Pure tones were added to the broadband noise signal with the generation of sine waves with frequency defined by the user.

Due to availability reasons, a commercial USB PC soundcard (M-Audio Fast Track USB) and musical microphone (Shure SM57) were used for signal acquisition and generation. Sound generation was performed by a 2-way vented box with a 12'' speaker and a titanium driver connected to a power amplifier (Wattsom DBS1500). The following picture depicts the actual system mounted:
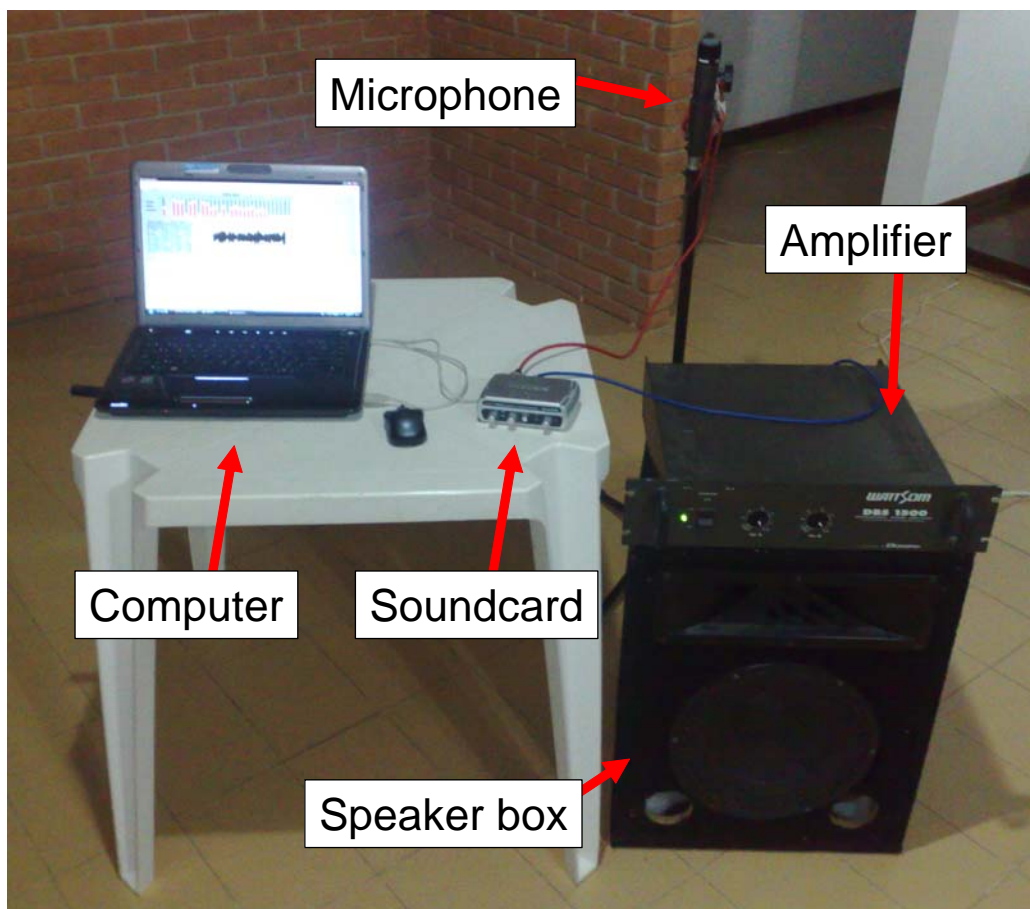

Figure 4 – Complete system mounted

The functioning of the whole system can be easily seen from the picture: the computer generates a noise signal, then send it to the commercial soundcard via USB port. The blue cable connects the soundcard output to a power

amplifier, which is connected to the 2-way vented box. The ambient noise, which will contain the influence of the noise generated by the speaker box, is then captured by the microphone, whose signal is fed to the input of the soundcard (red cable shown). Finally, the soundcard converts the microphone signal to digital form, and sends it to the computer, where all the data processing is performed.

The simplicity of the system poses some limitations that were taken into account. The microphone used is not designed for measurements, thus does not have a flat frequency response. Moreover, the lack of availability of an acoustic calibrator causes the calculated noise values in dB to be not accurate to reality. Despite these quantitative problems, the qualitative analysis of the results obtained remains valid, as will be described.

4. RESULTS

Target noise was set to a typical aircraft cabin noise. In general words, aircraft cabin noise is composed of a broadband component, generated from sources such as engines jet noise and boundary layer, and discrete tones centered at multiples of the engine blades passing frequency.

Figure 4 presents the condition which no noise is being generated by the software, as can be seen by the position of the volume controls for White Noise Volume, Pure Tone 1 and Pure Tone 2.
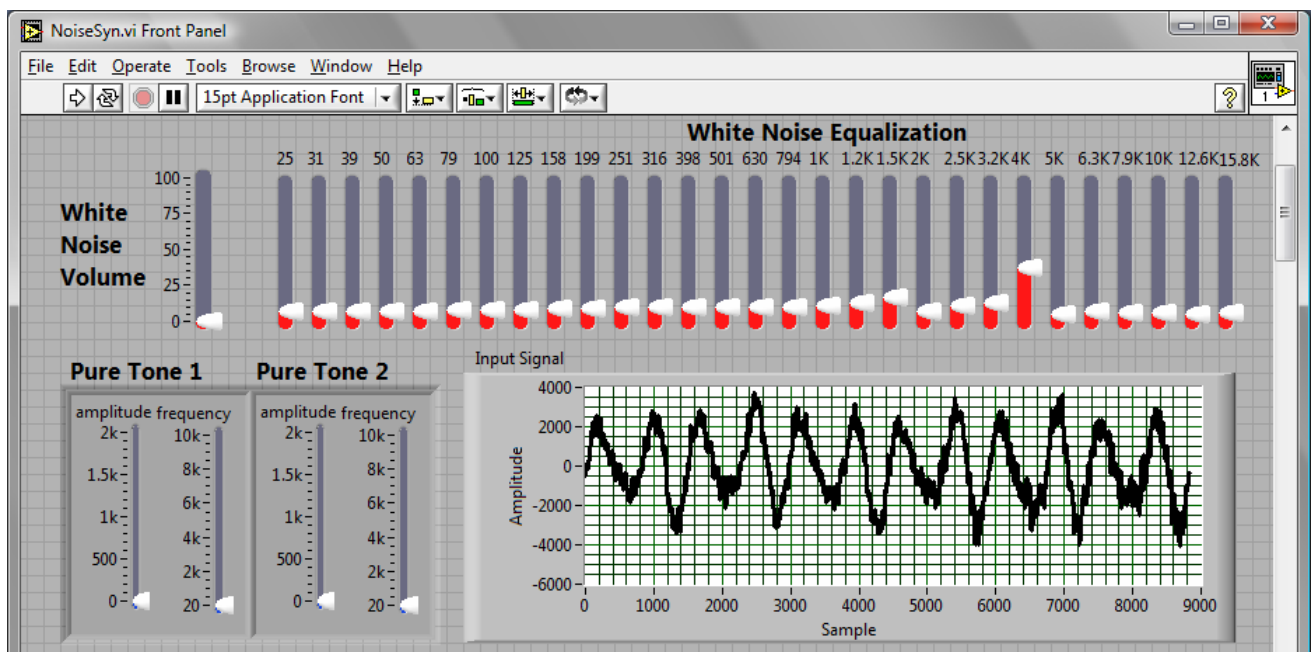

Figure 4 - Condition without any software control

Thus, the noise measured by the microphones on this situation does not have any influence of the software, and is basically background noise. The comparison between the measured noise levels and the aircraft target noise clearly shows a pronounced difference, in terms of spectrum amplitude and also spectrum shape, Fig. 5.
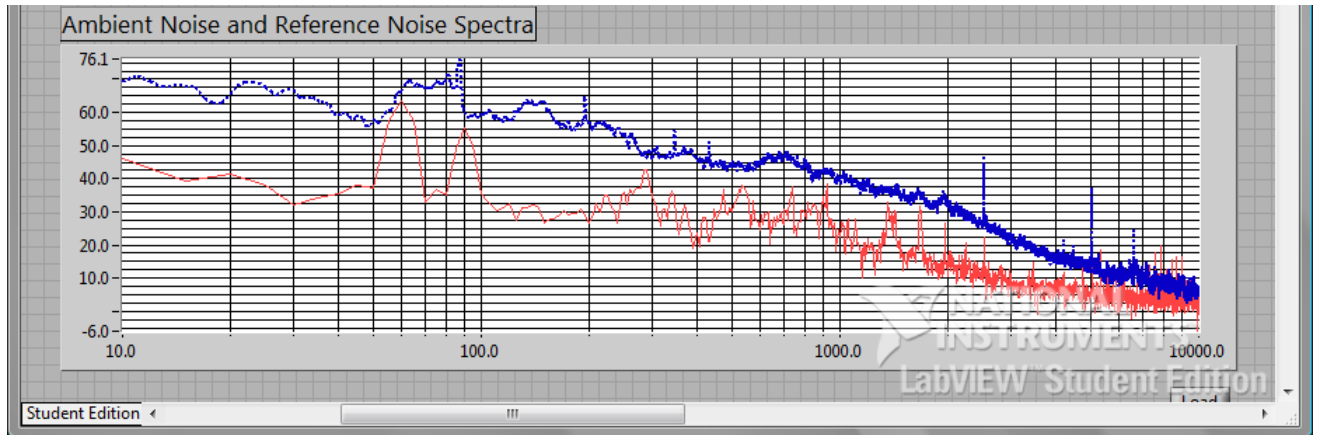
Figure 5 - Ambient noise and reference noise without software control

After proper adjustment, Fig. 6, of the user interface controls, the following result was obtained:
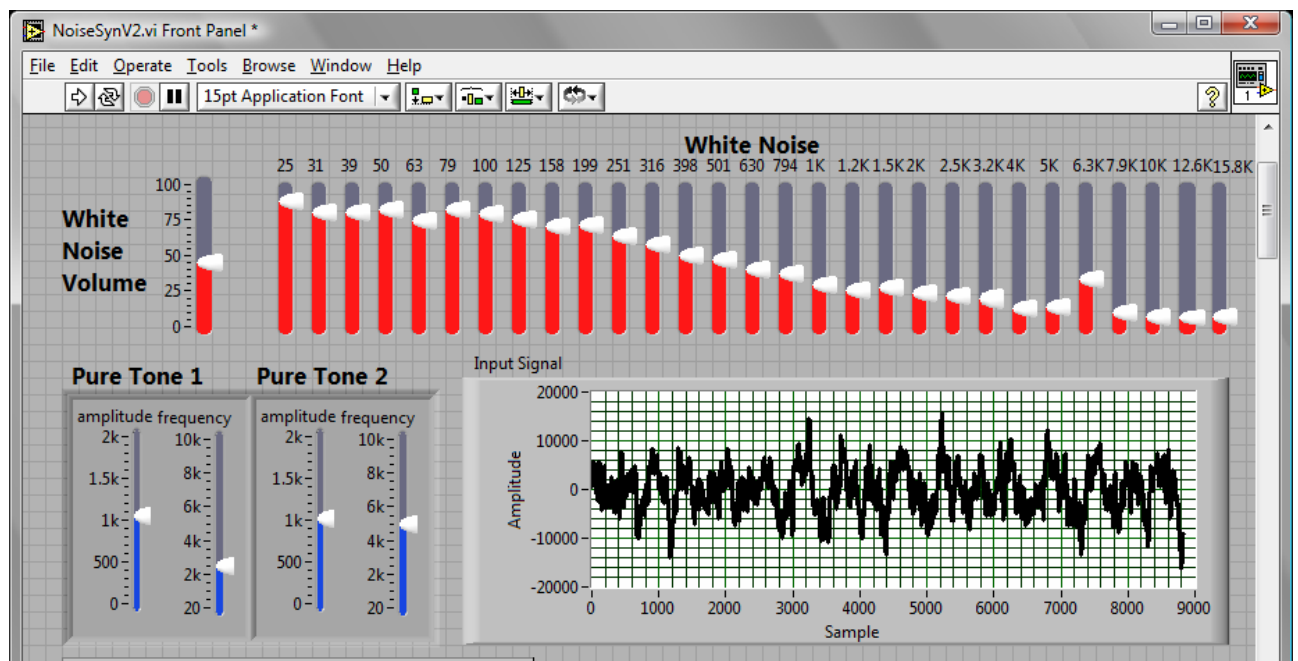

Figure 6 – Example of result obtained on real software utilization

After the adjustments it is possible to realize the software effect. In fig. 7 the software is generating a noise signal to be output to the speakers and influence the ambient noise levels. The user controls were set aiming to minimize the difference between measured and target noise levels. It can be seen that these two spectra have a very close match on this situation. The difference observed for frequencies below 40 Hz are due to physical speaker limitation.
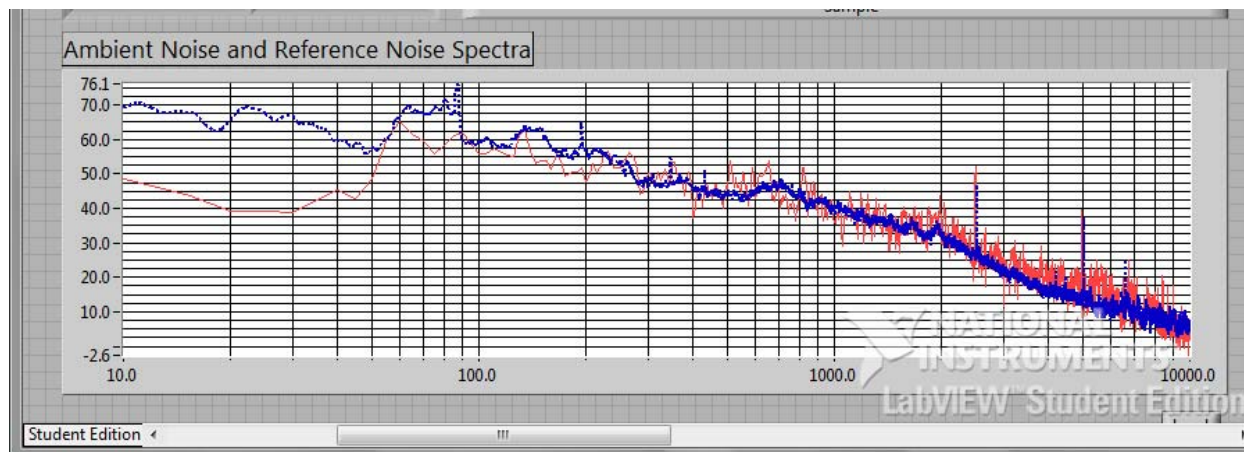
Figure 7 - Result after LabVIEW software send adequate signal to speakers.

Comparing fig. 5 with fig.7, it is clear the influence of the noise generated by the software on the noise levels measured by the microphones.

By changing the reference spectra used on the software, various scenarios can be simulated with the software. For example, if noise measurements for several seats of an aircraft are available, the user can evaluate the noise characteristics of any part of the aircraft, simply readjusting the controls to make the noise match the new reference spectrum

Additionally, subjective tests were performed with three different subject people groups, on different environmental conditions. It was only evaluated the similarity of the ambient noise produced by the software and that of a real aircraft. Despite the differences observed on the graphs between the measured and target noise, and also the errors imposed by the simple equipment used for the experiment, all the test subjects reported high similarity between the ambient noise generated by the system and the noise observed in a real aircraft operation. The lack of system calibration did not jeopardize the subjective results, as only the amplitude of the noise was affected, but not the general spectrum shape of the noise, which was the more important factor under analysis by the subjects.

5. CONCLUSIONS

The proposed approach for the acoustic instrumentation of a mockup proved to be effective in terms of subjective response. Thus the designed system can be successfully used on preliminary evaluation of human subjective response to different aspects of noise. Also it might be used in cases where it is not necessary too much precision on the ambient acoustic field, such as on customer evaluation mockups.

Next steps proposed include to perform tests using more appropriate instrumentation for scientific purposes, and also to broaden the level of the subjective analysis, including more specific questions to the test subjects. Automatic adjustments of the user-input parameters might also be pursued with active control techniques.

7. REFERENCES

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8. RESPONSIBILITY NOTICE

The authors are the only responsible for the printed material included in this paper.