What's In The Background?

A discussion paper on the impact of background noise on sound systems

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1.0. Introduction

The problem of how background noise affects a simulator is one that is not often considered, but there are a number of ways this can impact the successful certification of a Level D simulator. At the simplest end of the problem spectrum, the installation background noise can exceed the measured threshold for one or more aircraft/simulator test cases (particularly the quieter ones), and this may require exemption by the certification authorities, since there is often very little that the simulator manufacturer can do about such a situation. More problematic is a situation where a simulator is installed and tuned to meet the plot tolerances, and then is exposed to some external change in the background noise. As seen in the hypothetical situation below, the impact of such a change can very easily be test case dependent, and require that certain test cases require re–tuning, while others may not. Unfortunately at this time technology does not have a viable, simple solution for this issue. Based on current capabilities, if the background noise changes, then some, or possibly all test case conditions will require re–tuning.

2.0. The Problem

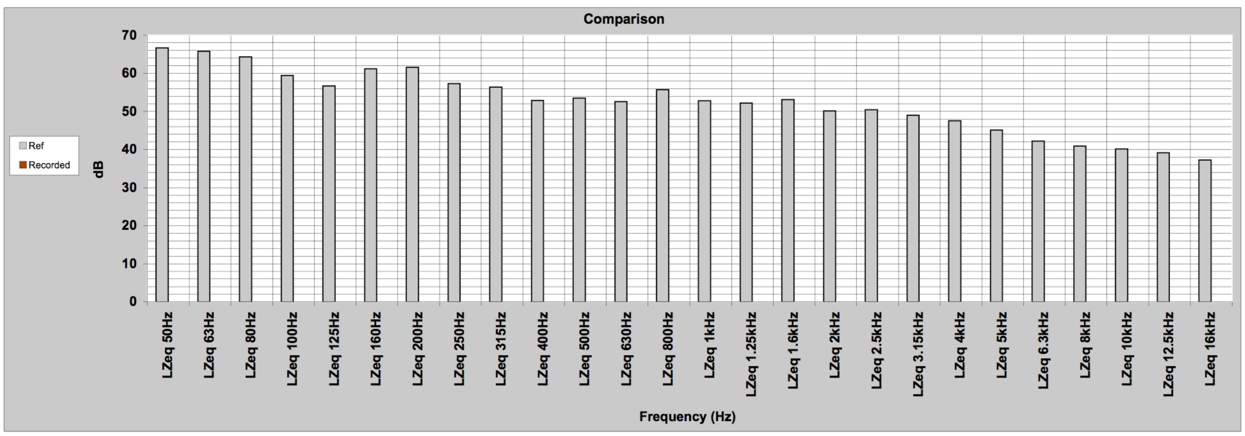
The current state of the art in sound simulation is almost certainly represented by the Level D full–flight simulator. In this case, not only is the sound simulation required to satisfy the subjective assessment of experienced flight crew, but additionally, the sound system is measured using a tool that represents the sound levels across the frequency range in 1/3rd octave bands known as spectral analysis. Industry has homed in on a requirement to match the spectral "signature" of the simulator, with the capture on an example of the real aircraft, within +/-5dB for each 1/3rd octave band. In practice the requirement is not quite so rigid with individual band exceptions not being uncommon with justification.

Typically simulators are installed in flight simulation centers, where there may be any number of other simulators installed. The construction of these centers varies, and includes custom facilities where there is one simulator per simulation bay with a concrete or block wall separating one device from the next, to large hanger—like halls with any number of devices installed side—by—side.

And it is now we get to the crux of the matter under discussion. The Level D testing methodology includes test case conditions for all phases of the aircraft operation, spanning eight defined cases including "ready for engine start", through to "final approach". Somewhat obviously, the sound levels experienced over these conditions varies with the aircraft type, and if the sound system is doing its job, the sound levels should match exactly those found in the original aircraft. Lets discuss the very first test case – "ready for engine start." The normal condition for this state is that the APU is running, cockpit electrical power is in the normal configuration, and generally the air–conditioning system is in the normal configuration. At this point some thought should be given to the likely environment that the original test aircraft was in during the audio recording for this test. Almost certainly the aircraft was out on the taxi-way, quite some distance from any buildings, and/or other equipment, and it is a requirement that consideration is given to avoid any other external noise affecting the recordings (like other aircraft operations).

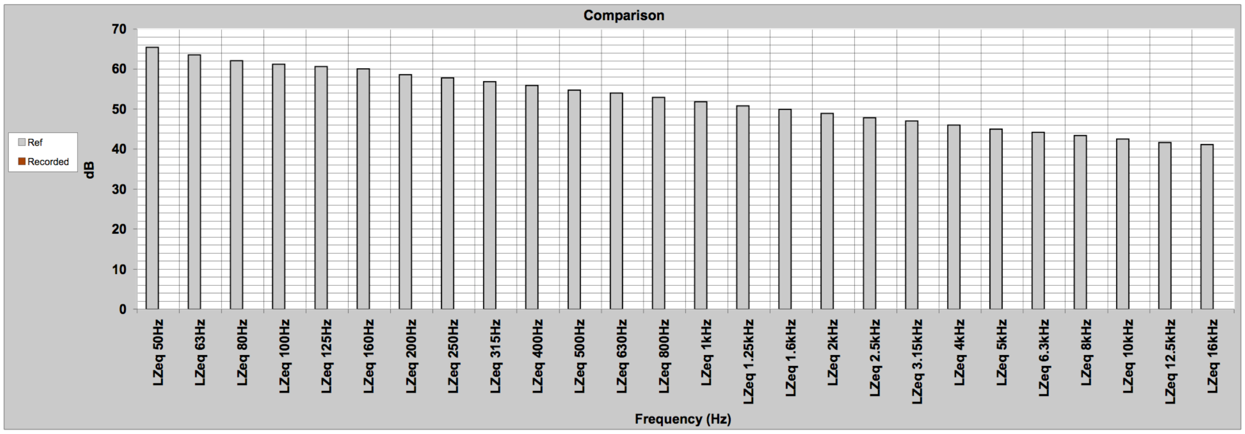
For a typical aircraft (lets use a 737NG) the recorded cockpit levels for the "ready for engine start" condition vary from 66dB at 50Hz, through 52dB at 1kHz, and drop to 37dB at 16kHz.

The 1/3rd octave spectral plot for this test case is shown below (Figure 1):



Now for the purposes of this discussion let's assume the background noise measured in the simulator follows the profile for "brown noise." Brown noise has a spectral density that is proportional to $1/f^2$, meaning it has more energy at lower frequencies. It decreases in power by 6 dB per octave, and is typical of noise profiles.

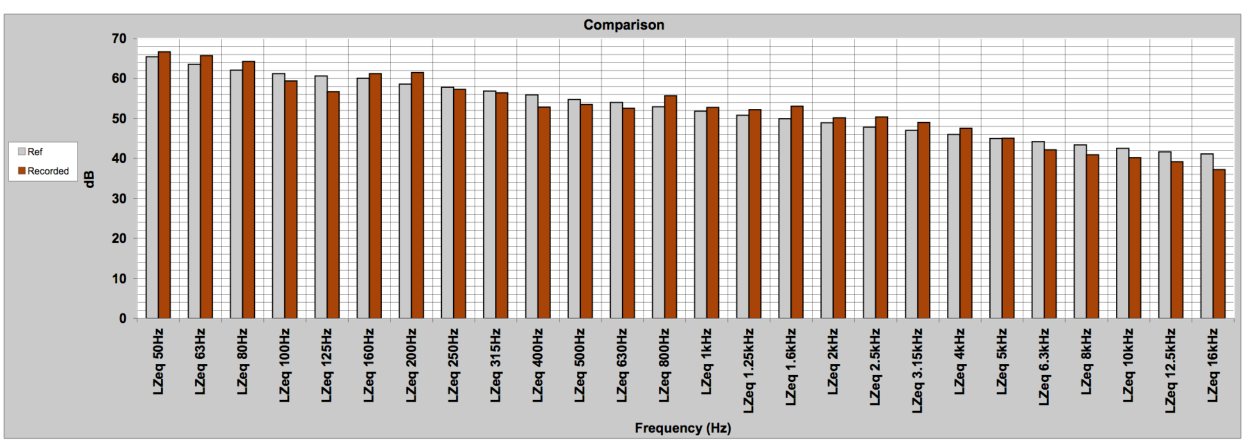
The plot for this noise would be as follows (Figure 2):



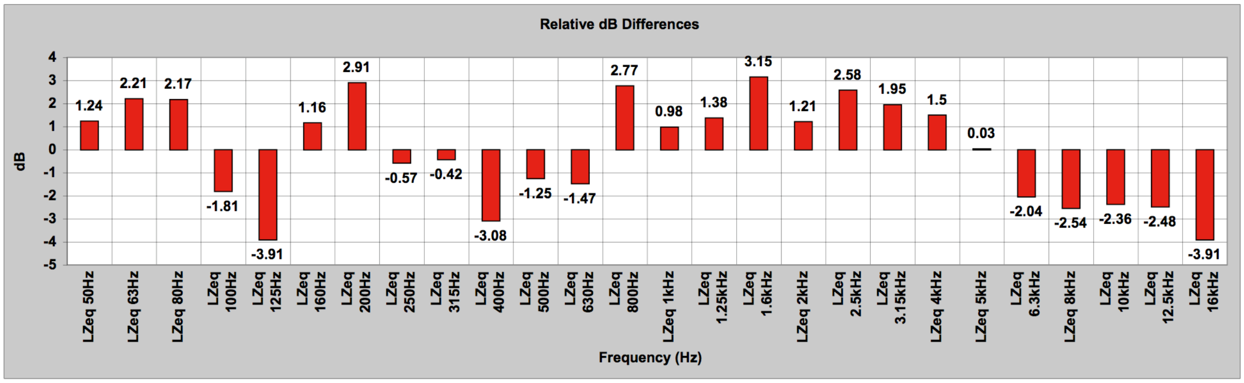
At this point it is important to understand a little bit about how sound levels work. Sound does not add linearly since sound is a measure of power, and uses log math. The first thing to recognize is that sound is measured using Decibels (dB) which is a logarithmic unit, which corresponds to how our ears happen to work. Therefore we need to recognize that sound levels do not add according to simple math, but according to log math. To take a real example: one sound that measures 20dB SPL, when added to another sound measuring 20dB SPL, does not produce a sound of 40dB SPL, but in fact would measure 23dB SPL. (Final SPL = 10Log (inverse LOG (SPLa/10) + inverse LOG (SPLb/10)), all values in dB).

So, if our sound system is perfect, we need to generate sound to "fill" the spectrum since we already have energy in some bands, and in fact as you can see from the following plot we have more energy than we need in some bands already. This is shown more clearly in the difference plot.

Comparative plot of background noise versus aircraft data (Figure 3):



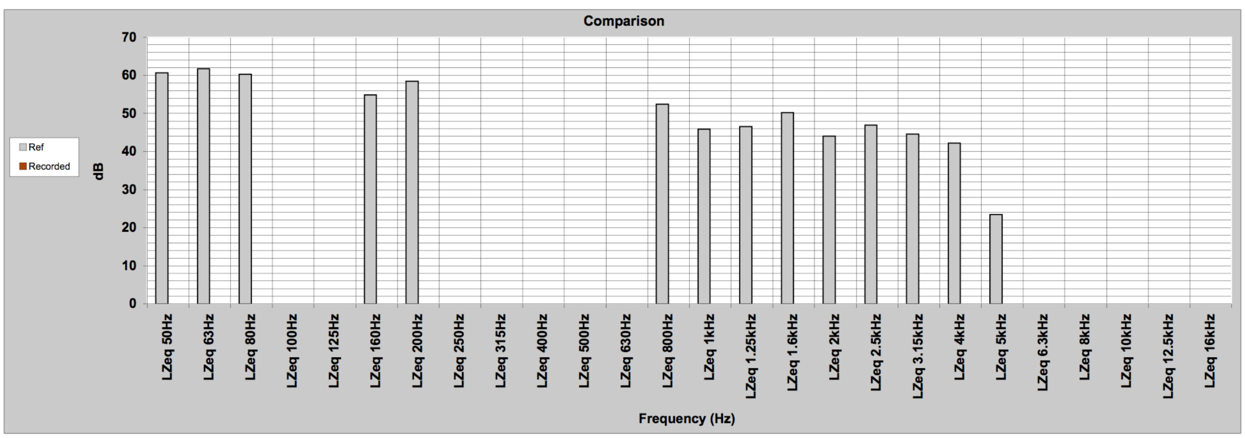
Difference plot (Figure 4):



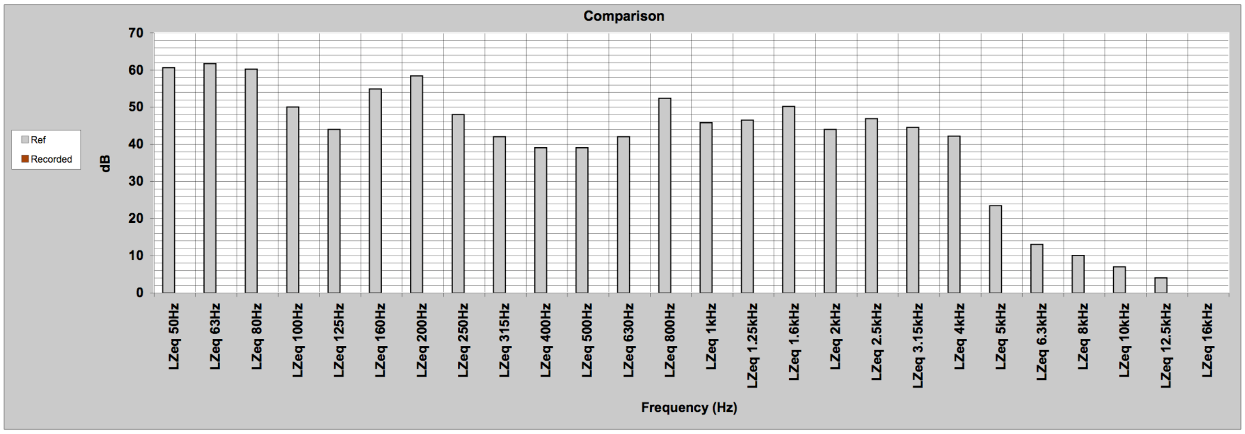
In the above plot, positive values mean the aircraft sound is greater than the noise floor, and negative values mean the noise floor is louder than the aircraft.

Looking at the above values it can be seen that there are certain frequencies that the sound system should not contribute any sound, specifically 100 and 125Hz, the range 250Hz to 630Hz, and 6.3kHz and above.

Therefore the sound system output signals will produce a plot as follows (Figure 5):



Naturally it would be rather hard to generate such a profile, particularly since many of the sounds are caused by wideband noise that is filtered (consider the sound of an air conditioning vent for example), and therefore it is more likely that the real output plot would approximate to the following (Figure 6):



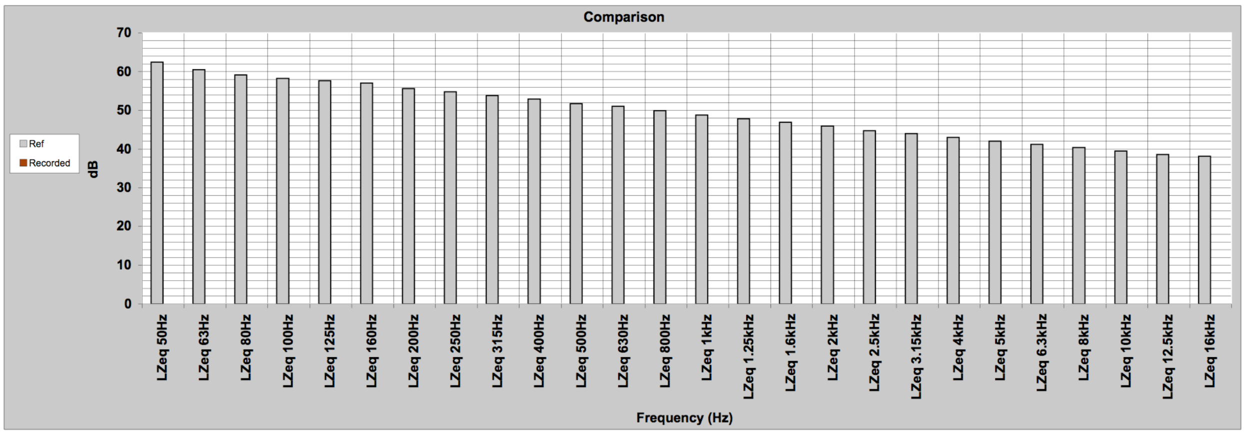
The basis for this is that any sound that is -10dB or below the measured signal level has negligible contribution to the overall level (less than 0.1dB), and additionally the most common filter used within the system has a -6dB/octave roll off.

Please be sure to understand that the **summation** of the sound system output **and** the noise profile, together form the sound profile measured in the cockpit.

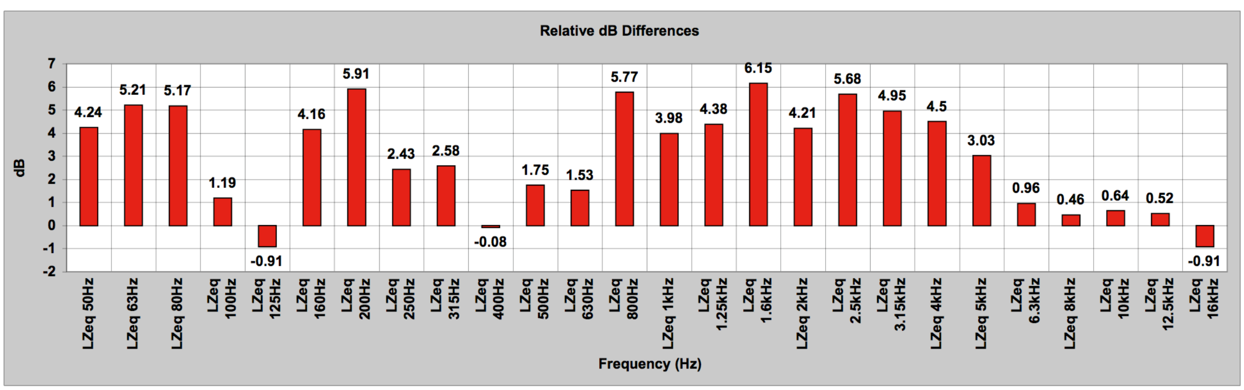
3.0. A Change In The Background

So, what happens if the background noise changes – any increase, somewhat obviously from looking at figure 3 and 4, will bury the aircraft sound below the noise floor, so we will move on from that condition for now, and consider what happens if the background noise floor *decreases*, and for now let's assume a linear decrease of 3dB per band occurs.

For completeness the plot of the background noise would become as shown below (Figure 7):



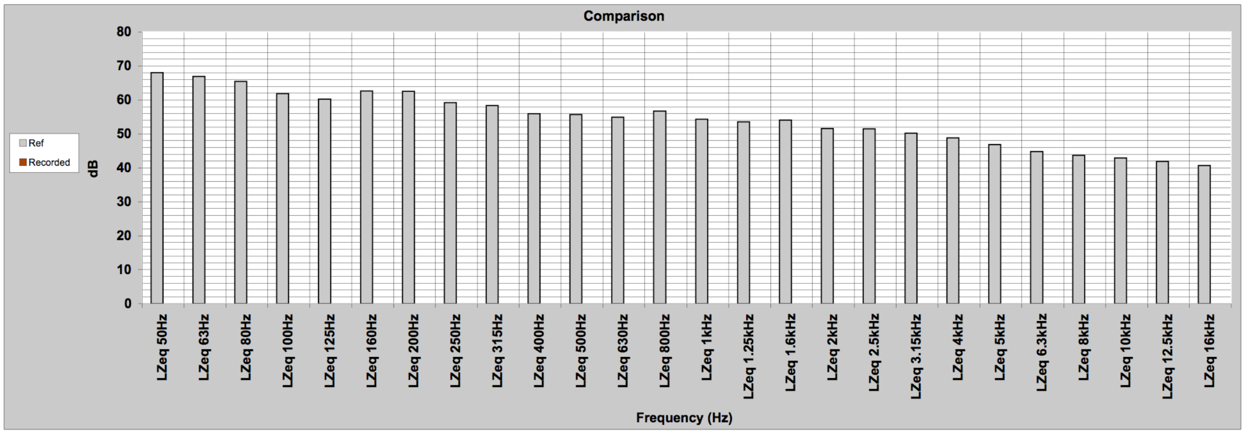
The resulting difference plot, showing the delta between the aircraft and background will become as shown below (Figure 8):



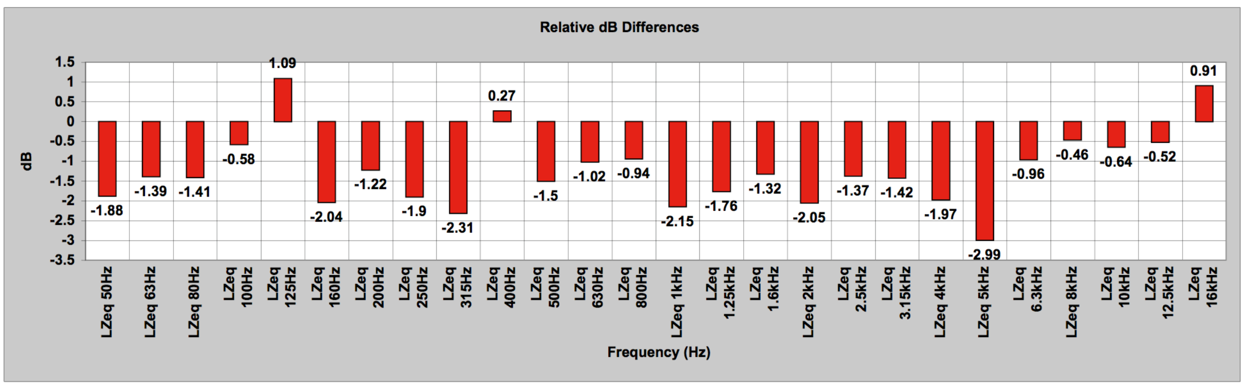
What figure 8 really shows is the contribution that the sound system must **now** provide to the overall sound environment. Note that in the original condition, out of the 26 bands included in the 1/3rd octave range, the sound system was required to contribute to 14 bands, but the revised condition now requires contribution in 23 bands.

What may be less obvious is that this cannot be achieved by simply tuning up the previous sound system configuration. Since the original "model" did not require energy in the additional bands, the plot will now become distorted.

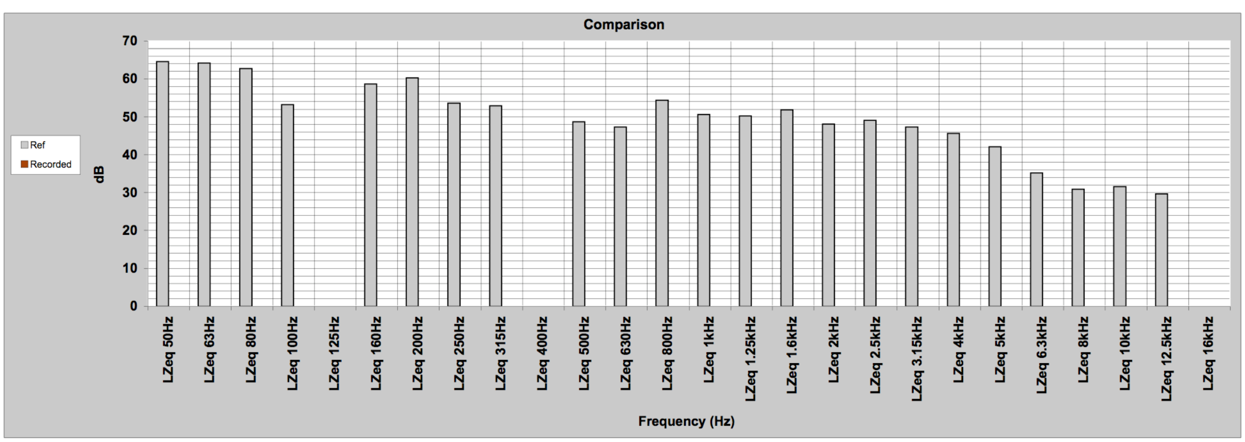
The following plot shows the plot profile following the background noise change (Figure 9):



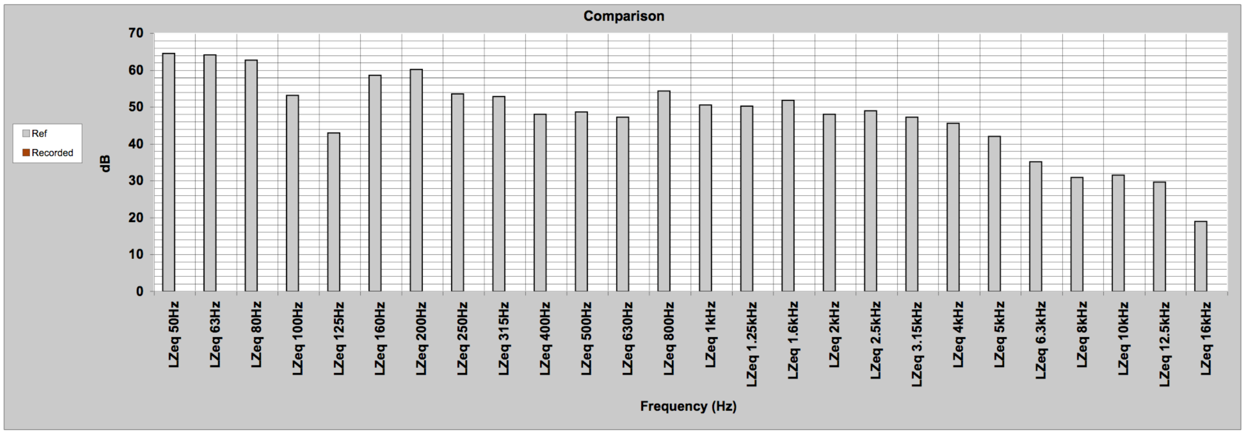
Comparing this to the aircraft profile produces the following difference plot (Figure 10):



On the surface this does not look to be a huge discrepancy, but of course this is all theoretical, so let's try to put this in perspective – what change to the sound system would be necessary to correct the profile, and return to a perfect match? Below is the sound system output necessary (Figure 11):

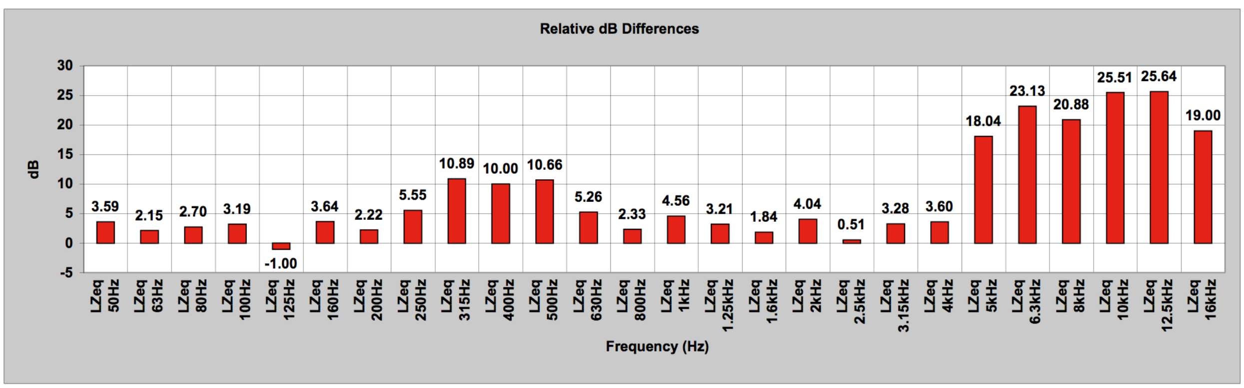


Which needs the same correction as used in figure 6, so the profile becomes (Figure 12):



4.0. So What Needs To Change

Now the really important issue is what is the sound system delta between what we generated previously versus what is needed now. This plot is shown below (Figure 13):



This plots shows the additional sound required to correct the frequency content to match the aircraft data. Generally, we see the bands that were previously contributing significantly to the sound output heard in the trainer need increasing by approximately the background noise delta of 3dB. However, of much greater significance are the two blocks of frequencies covering the ranges 250-to-630Hz, and 5kHz-to-16kHz, that in the original sound system implementation was entirely missing. In other words the original system did not produce **any sound** in these frequency ranges.

This is a significant impact to the sound system, since now it is necessary to add additional modeling objects, and determine the appropriate drive parameters. The question is whether the missing sound(s) is/are part of the air-conditioning (for example) signature of the aircraft, or some other sound? Naturally that is the task of the sound engineer working the system, but the nature of the problem is now evident. Therefore the impact of the background noise change is both additional modeling, and re-tuning of the existing sound objects.

What is less obvious is the follow-through impact on existing objects in the model. An ASTi sound model is built using sub-models and objects that represent the original sound sources identified from review of the original aircraft data recordings, so it would not be at all surprising to find objects labeled “APU”, “recirculation fans”, “boost pumps”, etc. Each of these objects generates the sound for that particular source. However changing the background noise may cause changes to many elements of the model, since, not only will the absolute amplitude of some of the contributing elements change, but also additionally the frequency content of those signals may need adjusting. The magnitude of these changes will depend to a large extent on the relative sound level of the aircraft sounds to the background, hence these changes will not be linear in their application, or necessity.

5.0. Real World

In the fictitious example used above, the noise floor of the simulator was modeled as “brown noise”, which is a weighted noise profile, where noise is assumed to be random frequencies. In the real world the background noise experienced in a flight simulator will generally be a little more complicated, and will comprise signals from various sources, which complicates our problem. What we may well see is noise components sourced from the simulator local air-conditioning (required to keep the cabin space and electronics cool), equipment noise from the simulated cockpit instruments and displays (fans, and blowers in particular), external air-conditioning from the building installation and quite likely noise from other simulators in the vicinity. This latter component can vary from virtually none, to significantly invasive. Of most impact is noise from support equipment such as hydraulic motors, and depending on the age of this equipment can be ‘very loud’. A recent example indicates a tonal peak at 125Hz of 62db SPL (Z-weighted) and at 250Hz of 58dB. Both of these values are some +5dB above the cockpit noise recorded in a 737NG for the “ready for engine start” test case condition.

The real problem with such tonal peaks is that they will change based on whether the simulator associated with the sound source is running, and indeed whether the simulator is powered on or off. Obviously the noise profile will look greatly different if the source simulator is powered down for maintenance. Based on this, it is vital to be aware of not only the background noise profile, but also the source for the significant elements of the noise signals. Since it is a requirement to re-run a certain percentage of the QTG every few months, any change in the background noise has the potential to cause the sound system plots to change and quite conceivably fail to be within tolerance as a result.

6.0. Conclusion

The first thing to recognize is that the background noise floor of any sound system defines the quietest sounds that an operator inside that space can perceive, hence it is greatly desired that this noise floor is as quiet as possible. It must be recognized however that the simulator must be cooled, and that noise from electrical equipment fitted to the simulator is unavoidable (though should be considered when equipment is selected). Additionally external noise is entirely outside of the control of the simulator manufacturer, and particularly in the case of low frequency sound, virtually impossible to block from reaching the cockpit space. Obviously sensible application of sound blocking materials should be applied to reduce sound leakage, but this cannot be expected to solve this problem.

Most important is a recognition, both in the QTG documentation, and in discussions regarding the simulator environment, that the effect of background noise is fundamental to the sound system, and that the objective spectral analysis plots, particularly for the quieter aircraft test case conditions, can, and will be, affected by any changes to the noise environment that the simulator is exposed to. It must also be recognized that a change to the noise environment, whether temporary, or permanent will affect the sound plots, and that re-tuning will be required if the noise changes after the “final tuning” has taken place for certification. The nature and extent of that task cannot easily be quantified, since it is a non-linear function of the frequency content and amplitude of the noise itself, and the nature of the aircraft sounds.