The mathematics of model flying: 2 The decibel scale

Essential equipment: A bag full of ice cubes to go on your head.
Risk assessment: Remove from reach anything that you might use to harm yourself.

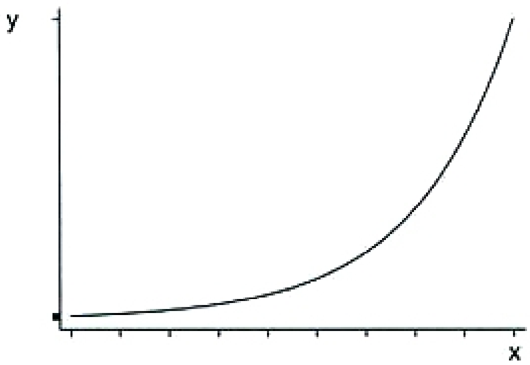
The decibel scale is much misunderstood. It is used in a variety of circumstances involving power. Amongst those relevant to us are transmitter power and engine noise perhaps from glider tugs. There are two topics that I have always found difficult to explain simply. The first was how jpeg compression works and the second was the decibel scale. O yes, I forgot. How the Wimshurst Generator works.

Belt up. Here we go! Oh that's rather good isn't it? Belt up.

Bels

In fact the scale is bels, each of which is divided into ten decibels. It is so-called in honour of Alexander Graham Bell. It is a numeric scale but it doesn't usually have a zero value. It compares one value with another. It is a ratio so does not have a unit like watt or volt.

An electrical power example might make it clearer. We all know what a watt is. One watt is one watt. Always. Except perhaps on social media. However suppose we compare two different powers, say 1 W and 10 W. On the bel scale the 10 W is 1 bel larger than the 1 W. If we compare 1 W and 100 W these are 2 bel different. Each time you up by one bel you increase the power ten times. 1 W and 1000 W is 3 bel and so on. The number of bels is the number of zeroes after the 1. This is called a logarithmic scale and looks something like this. It is non-linear, meaning not a straight line.



If the second quantity is less that the first then the number of bels is negative. For example if the first is 10 W and the second is 1 W you get -1 bel.

Decibels

The bel is divided into ten parts called decibels (dB). Power ratios are usually given in decibels.

This table shows how it works:

Power	dB	(in bels)
1	0	0
10	10	1
100	20	2
1000	30	3

10000	40	4
100000	50	5
1000000	60	6
etc		

To make things worse the decibel jumps are not equal in size either. They are logarithmic too. A dB at the high end of the bel will be bigger than one at the bottom. Here are some approximate values:

dB	Ratio
0	1 (same value)
1	1.3
2	1.6
3	2
4	2.5
5	3.2
6	4
7	5
8	6.3
9	8
10	10

Sometimes we pretend that one quantity is not being compared with another. We talk about 30 dB of electrical power or 82 dB of sound power as though it is a real value. In fact we are comparing the measured quantity with a zero that we have made up, an arbitrary zero. In reality there is a true zero an all scales. On sound it would be when all air molecules have stopped moving. That, of course, is absolute zero (-273 ºC). However this is such a low temperature that it is impracticable as your ears would crumble and drop off. Electric power is easier as it would simply be zero current.

Another bag of ice needed (you can skip this and jump to practical examples)

And now the final complication. If we are using the dB scale for electricity or sound we need to look at what causes the power. In electricity it is the voltage and in sound it is intensity or amplitude of the vibration. In both cases power goes up with the square of these.

Using electricity as the example, power = V^2 / R

This means that if we take the ratio of the voltages, the power ratio will be the square of the voltage ratio and so the dB will be doubled. Thus a 3 dB voltage rise will give a 6 dB power rise.

Two practical examples of power dB ratios

Engine noise

This is measured on the dB(A) scale, at least it is for the UK British Model Flying Association purposes. Most sound meters use that scale too. It is even more complicated as it measures the sound in a way that roughly equates to our hearing. It gives more weight to the frequencies between 2 and 4 kHz that our ears are most sensitive to and hence damaged by. Zero on this scale is 2×10^{-5} pascal or twenty micropascal where one pascal is one newton per square metre. The specified 82 dB for acceptable engine noise is therefore a little over a hundred million times more than the zero, or 2 x 10^3 Pascal. You could work out what the actual force on an eardrum will be from the pressure times the area of the drum.

Abandon all hope all ye who enter here! Decibels are the tenth level of hell.

OK I give in. I'll put on my ice pack and calculate it. Force is pressure times area. The ear drum is about 5 x 10^{-5} square metres. Taking the 2 x 10^3 pascal value for 80 dB pressure this gives a force of 10 x 10^{-2} or 10^{-1} newton. One newton is about the weight of an apple. So this is the weight of a tenth of an apple, roughly the core. That's more than I expected. And all bashing your eardrum. And no I won't do it in Roman imperial units, though you are welcome to. I can lend you a Roman wax tablet and scriber to do your working on and will mark it QED when finished.

Transmitter power and range check

When we do a range check on 2.4 GHz we divide the radiated power by about 30. This lies between -1 bel and -2 bel (10x and 100x). Unsurprisingly it turns out out to be -14.8 dB. It is minus because the full power value is more than the reduced test value.

Damage to hearing from engines

When it comes to damaging levels of sound, the magic number is 85 dBA. Researchers agree that extended or repeated exposure to sounds of 85 decibels or above can cause permanent hearing loss or other damage. Many musicians, including acoustic orchestral players, suffer severe hearing loss due to the sound levels in live concerts. At heavy metal or reggae concerts some people like to sit almost inside the bass speakers and some suffer bleeding from the ears.

Three main factors influence the severity of hearing damage:

- Sound level (how loud the sound is)
- Proximity (how close you are to the sound)
- Time (how long you are exposed to it)

The louder the sound, the less time it takes for the damage to take place. You now know that for every 10 decibels, the power of the sound goes up 10 times. At 85 decibels, the maximum recommended exposure time is 8 hours. But by 100 decibels, the exposure limit drops to 15 minutes, and at 10 decibels more (110 dB), the exposure time plummets to just one minute. Exposure to such sounds any longer than that could result in permanent hearing loss or tinnitus. Part of this section was from: https://www.miracle-ear.com/blog-news/what-is-loud-decibel-chart

And that is also why technicians who are working on Formula 1 engines or who are near to jet engines always wear ear protection.

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