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SEA-TAC Aircraft Noise Study 2

Mr. Richard Aramburu
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Dear Rick:

This letter is in response to a request from you in our telephone conversation last Wednesday. You asked me to provide you with comments on the appropriateness of the L_{dn} metric for rating aircraft noise in neighborhoods surrounding Sea-Tac Airport and to discuss the data that is used for input to the Integrated Noise Model (INM) that is used by the FAA and others to produce the L_{dn} contours for airports, such as Sea-Tac. These two items are discussed below.

NOISE METRICS

The purpose of any noise rating scheme is to associate a single number with the noise being evaluated which, when compared with other noises, will rank order the noises in terms of human perceptions of loudness or annoyance. This is not a simple task.

Noise is "Unwanted sound." Therefore, not only the physical properties of the noise must be considered, but also many factors that depend on the nature of the noise and the way in which humans respond to it must be considered. This topic is the basis of a much research and has been vigorously studied since the invention of the microphone. A good reference on the subject can be found in my book[1].

The principal physical properties of a noise that play a part in the subjective evaluation of its annoyance are:

- sound intensity
- frequency (pitch) distribution
- fluctuations of the above over a given time period

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[1] *Evaluating the Noises of Transportation,* The University of Washington Press, Seattle, 1969.

- extraneous factors which affect the way we perceive noise

Intensity

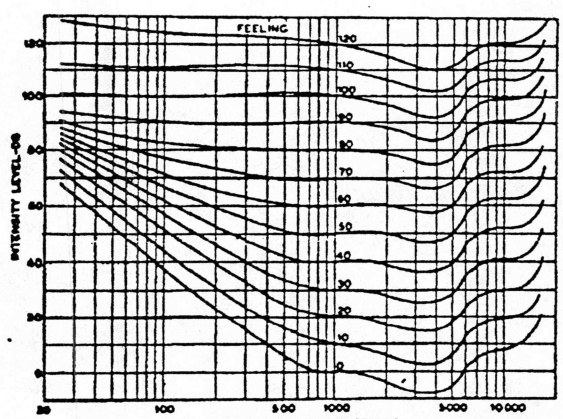
It is a relatively easy task to measure and record these quantities with microphones, electronic devices, and computers, but when you consider all the possibilities of combinations of these properties, is becomes a formidable undertaking to assign consistent numerical values that will provide the necessary rank ordering of a variety of noises.

The relation between the subjective evaluation and the physical measure of intensity seems to be straight forward, and this is where the concept of the decibel[2] comes in. The decibel scale confuses many people because it is a logarithmic scale, but it can be shown that when the perception of a change in the stimulus is proportional to the existing level of the stimulus, a logarithmic scale should be used. It is good to remember that an increase in level of ten decibels corresponds to a subjective evaluation of twice the loudness or annoyance. That is, 60 dB is twice as loud as 50 dB and 90 dB is half as loud as 100 dB.

Because of the logarithmic nature of the decibel, noise levels do not add and subtract the same way as apples and oranges. That is, if two noises with the same sound pressure level, for instance 70 dB, are added, the total noise level is 73 dB.

Frequency Distribution

Next, one must consider the frequency sensitivity of the human listener. The first definitive evaluation of this factor was performed in the 1930's by a Fletcher and Munsen[3]. On the basis of their research, they published the "Fletcher-Munsen Curves of Equal Loudness for Pure Tones," which were regarded at the time to be the definitive descriptor of the way in which humans perceive sounds of different



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[2] This unit is actually one-tenth of a "Bell" and it was named in honor of Alexander Graham Bell, which is why we abbreviate the unit "dB."

[3] Fletcher, H. and Munsen, "Loudness, its Definition, Measurement and Calculation," J. Acoustical Society of America, v 5, pp 84-97, 1933.

frequencies. These data are presented in the accompanying figure.

The result of their work was widely used and was the basis of the foremost of the rating schemes used to evaluate noise, the "A-weighted sound pressure level," or the "dBA." The A-weighting scheme generally follows the contours of the Fletcher-Munsen equal loudness curves for sounds that are near the threshold of hearing for the average listener. It shows that we are most sensitive to sounds in the frequency range from about 1,000 Hz[4] to 6,000 Hz. We are much less sensitive to low frequency sounds.

Outside the acoustical profession it is seldom noted that there were also two other weighting schemes that were proposed for measuring noises of greater intensity than those which were to be rated by the A-weighting scheme. These are called the "B-weighting" and the "C-weighting," and they approximate the Fletcher-Munsen contours for moderate and loud sounds, and it was assumed that these would be used for evaluating loud noises.

The complexity of using three different weighting schemes and the confusion that might result from reporting measurements led researchers in the field of psychoacoustics to attempt to determine if one of these schemes correlated better with the subjective evaluation of loudness of human listeners. It was concluded that the A-weighting scheme performed better at rating a wide variety of sounds than either the B- or the C-weighting schemes. As a result of these studies, most simple noise measurements are now made using A-weighting.

Until recently, good quality sound level meters (SLM's) came with these weighting networks built into them. The B-weighting scheme is so rarely used that it is frequently omitted from even high quality meters. Even the C-weighting may be omitted, but is still provided in some instruments.

When greater accuracy or finer detail is required or desired, acousticians use more complicated means for evaluating noises. Two examples of these rating schemes are the Stevens' Loudness Level L_{ℓ} and the Perceived Noise Level L_{pn}. (Sometimes written PNL.) Both of these schemes require that the sound be divided into 1/3 octave bands. (Or at least into 1/1 octave bands) The contribution of each of band to the over all noisiness or annoyance is then tallied to give the final level. Loudness Level evaluates the loudness of a noise, whereas, Perceived Noise Level evaluates the annoyance. These schemes are both recognized as being more accurate for rating the particular aspect of

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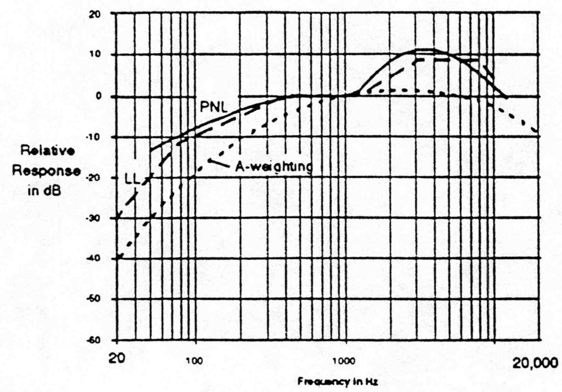
[4] The unit of frequency is the "Hertz," abbriviated Hz, which is named in honor of a German scientist, Heinrich Hertz, who studied the phenomenon of musical pitch. It corresponds to one cycle per second.

noises than the A-, B-, or C-weighting schemes, but they require computation and not available on hand held SLM's. The figure at right shows the similarities and differences in these three noise rating schemes. Note in particular that the A-weighting de-emphasizes the low frequencies and the critical range from 2,000 to 10,000 Hz more than the other schemes.



The A-weighted noise level has become the de facto scheme for rating environmental noise, and in particular, the L_{eq} and the L_{dn} (A-weighted, of course.) are frequently used for this purpose. To my knowledge, neither the L_l nor the L_{pn} is used anywhere in the world to describe the noise environment at a particular location.

Variations on Noise Level with Time

These schemes all work reasonably well at ranking the severity of steady noises or noises with similar temporal profiles, but they do not provide a methodology for ranking noises that have differing time histories. In order to overcome this deficiency, several schemes have been devised, but the most common method is one in which the time varying noise level is "averaged." This is the basis of the "Equivalent noise level metric," L_{eq}. This is sometimes defined as, "the level of an equivalent steady noise that has the same energy as noise from the time varying event." Of course, since the sound pressure level is a logarithmic measure, the averaging scheme has to take this into account. For example, consider the average of a noise that is 60 dB for half the time and 70 dB for the remainder of the time. Since at 70 dB the noise has ten times as much power as at 60 dB noise, the L_{eq} is 67.4 dB. For completeness, when the L_{eq} metric is used, one should indicate the period of time over which the average was taken, e.g. L_{eq}(1 hr). In computing an L_{eq} any weighting can be used, but it is usually used with the A-weighting.

It is generally accepted that we want peace and quiet during the night-time hours. For this reason, acousticians sometimes add penalties to noises that occur during the hours of night-time. The day-night noise level, L_{dn} is a 24 hour L_{eq} where noises occurring during the hours between 10:00 pm and 7:00 am are penalized by ten decibels. This can be carried further, and the "average" L_{dn} over a "typical" year can sometimes be used, as is the case in FAA airport noise studies.

Rating Noises from Single Events

The DEIS refers to the SEL, or Single Event Noise Level, which is an interesting metric that is used to rate an isolated event. The SEL is a similar to an L_{eq}, but it differs in that the noise level is "normalized" to a one second period, that is, the SEL is "the level of an equivalent steady noise that lasts for one second and has the same energy as noise from the time varying event." The difference between this definition and that for the L_{eq} is in the phrase that is underlined. The SEL more accurately rates the magnitude of a single event than an L_{eq}, even if the L_{eq} is taken over the period of the event. (If an L_{eq} is taken over a longer period of time, it will usually be lower the L_{eq} over the period of the event, and certainly lower than the SEL.) Of course, when it comes to events like sleep interruption, the L_{max} is probably more accurate in predicting the effect of a single event.

Karl Kryter[5] has devoted a great deal of effort to develop a scheme for rating time varying noises, in particular, the noises from jet aircraft. His Perceived Noise Level scheme has been modified to rate single events called the Effective Perceived Noise Level, L_{epn}. (Or EPNL) This scheme is a normalized L_{pn}, (with corrections for pure tones) similar to the SEL. The biggest drawback to using this scheme is that it requires much computation to compute a single L_{epn} value. (It certainly is not a measure that can be read from a hand held SLM.) This rating scheme is used in certification of aircraft in the US (See Part 36 of the Federal Air Regulations.) and elsewhere.

Rating Environments with Multiple Noise Events

It has long been recognized in the noise community that noises that are not constant in time are more annoying. For example, Ira Hirsch states[6],

> *The number of events is a very important predictor of community annoyance.*

It is surprising that the noise control profession has not settled on a measure that includes this factor in rating environmental noises.

In the 1960's Richards developed a metric called the Noise and Number Index, NNI, which was a combination of the noise exposure from individual (aircraft operations) events and the number of events comprising the exposure of the community. This metric

aircraft x events

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[5] Kryter, Karl, *The Effects of Noise on Man*, McGraw-Hill.

[6] J. D. Chalupník, *Transportation Noises*, University of Washington Press, Seattle, Washington, 1970, pg 336.

was popular for a briefly in Great Britain. The principal feature of this metric scheme was that an "average" level for the intruding stimulus was determined for a given period of time. To that was added a factor for the number of events that occurred in the period of time. The factor was expressed in decibels, but was based on the power law; that is, the factor increased by three decibels if the number of events increased by a factor of two. Effectively, this is the same relation that is found in the "averaging" schemes described earlier in this document.

Another scheme that part has been ignored for the most by the profession addresses the problem, in my opinion. This scheme is called the Noise Pollution Level. It is defined by the following equation:

$$L_{np}(T) = L_{eq}(T) + \kappa\sigma$$

where κ equals 2.56 and σ is the standard deviation of the noise level during the period of evaluation, T. If the noise is constant, like the noise from a ventilation fan that runs all the time, then σ is zero, and the L_{dn} is the same as the L_{eq}, but if there is a relatively constant background with a few very loud events of short duration during the period T, then σ will be large, and the L_{np} will be larger than the L_{eq}.

One of the reasons given for rejecting of this scheme is that various factions can not agree on the value for the factor κ. This is a very important factor in evaluating noises like aircraft noise, where the peak values of the noise from an individual operation can be many decibels above the background noise level. Another problem with this scheme is that the L_{eq} is implicitly the A-weighted noise level, and it can be seen the second figure presented above that this scheme under estimates some of the components of the spectrum of aircraft noise. The most common complaint that I have heard is that the low frequency noise created by the current mix of heavy aircraft are not adequately evaluated by the current schemes.

Integrated Noise Model

I have not used the INM model, but I have used similar models, and I know what goes into these models. The information given below is based on this knowledge. In some cases, the exact way in which information is provided to the program may be slightly different from the way stated. For example, the number of planes following a particular track may be presented as numerical values, or as percentages of the total number of operations.

The Integrated Noise Model, INM, is a computer model that uses a large database of information that has been obtained for the current fleet of aircraft used in commercial and military service to predict the noise exposure at given locations around commercial airports in the US. In its simplest application, the INM will be used to compute the SEL for a single event at a particular location relative to an airport. The INM can also be instructed to compute the L_{dn} at a particular location for any combination of takeoffs and landings on one or more runways. The INM can also be programmed to compute and display the contours for a given set of takeoff and landing events.

Although it could be programmed differently, the INM normally provides annual average L_{dn} information.

Factors Used in Computing an L_{dn} Value with INM

The following factors are used as input to the INM model.

- Location of the receiver relative to the airport
- Which runway(s) is used
- Flight track of the aircraft on the ground
- Number of takeoffs and landings
- Number of takeoffs and landings that occur during the night
- Aircraft type
- Aircraft weight (on takeoff)
- Whether noise abatement procedures are being used
- Percent of time a particular configuration will be used (runway, flight track, etc.)
- Elevation of airport

Factors that Are Not Used by INM

- Elevation of receiver (relative to the airport)
- Topographical features (hills, ravines, etc.)
- Presence of large structures near to the receiver (or source)
- Deviations from the presumed flight path or procedure by the pilot

- Noise from other sources
- Background noise

The INM Data Base

In the process of certification an aircraft for service as a commercial aircraft for use in the US market, enormous amounts of data are collected on many factors, one of which is the noise created by this aircraft under operational conditions. If the airplanes are to operate in the US., they must meet the requirements of FAR Part 36, so most of the testing is aimed at satisfying the requirements specified by that document. The results of these tests and others as well have been stored in the INM program. By using these data and the physical laws of acoustics, it is possible to compute the SEL levels at a given point relative to an airport for aircraft on takeoff and landing. (Note, that aircraft are restricted in their profiles to a rather strict path of flight {or so it is said} and so the position of the aircraft relative to the airport at any instant is fairly well defined. Also, the power settings and other factors that affect the noise from the aircraft are similarly prescribed and known.) Landings and takeoffs are treated independently.

These data are stored in tables that give the SEL for particular aircraft and configuration at a specified distance down the flight track and at a specified distance from the flight track. For certain aircraft, several tables may be provided, (For example, there may be several tables for the Boeing 747-400 takeoffs, depending on the distance to the destination.) or one table may be shared by a group of aircraft types. (For example, all two engine turboprop aircraft with gross takeoff weight less than 12,500 pounds could share a table.)

Number of Operations

The number of operations is specified to the INM by the annual average number of operations that a particular aircraft type will follow a particular flight path. In programming the INM, it is important to know the percentage of time that aircraft use each of the runways, and in which direction the aircraft flow. For instance, in Seattle the flow of air traffic is to the south about sixty percent of the time. The remainder of the time the flow is to the north. During south flow days, the aircraft can use either the left or the right runway, which are designated 16L and 16R. The percentages of the flights that use these depend on several factors, but the historical values are used for specifying the distribution for the purposes of the noise model. Note, that heavy aircraft will normally use 16L for takeoff because it is the longer runway.

The number of operations per hour is not specified, except that the number (or percentage) of operations that occur at night (between 10:00pm and 7:00am) is used in the computations.

Flight Tracks

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If one wanted to orient an airport so that it would create the maximum noise impact on the Puget Sound Basin, they would line it up exactly the way it is oriented today. The runways are lined up so that airplanes must fly over Seattle to the north and the cities of Sea-Tac, Desmoins, Federal Way, Tacoma, and Auburn to the south.

The paths that aircraft follow are well defined in the area close in to the airport. On landing, the aircraft line up with the runway that they will land on a long way from the airport and approach on a three percent glide slope. Using the "Four Poster" plan, they intercept the glide slope a little to the north of the University of Washington campus on south flow days and over Milton on north flow days. On takeoff, the aircraft follow the same track near the airport, but after they reach 3,000 ft altitude above the airport they start turning toward the destination. Just where the turn begins fdepends on the type of aircraft and how heavily loaded it is. Small feeder turboprop aircraft make these turns and intercept the glide slopes at lower altitudes under visual rule operations.

The L_{dn} 65 contours are symmetrically aligned with the runways and show how consistent the flight paths are in the area near the airport; however, plots of the flight tracks outside these contours depart from this alignment and cover the populated areas to the south and north of the airport.

Sincerely,

James D. Chalupník