A possible criterion for wind farms

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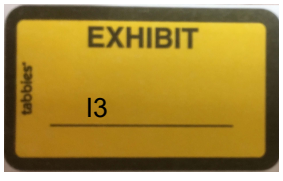

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A possible criterion for wind farms

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Opposition to wind farm noise is not abating and shows no sign of doing so in the future. In a January 2017 paper in Sound and Vibration, Hessler, Leventhal, Walker and Schomer come together to report that independently they have come to about the same conclusion for a proper threshold of wind turbine noise. The same A-Weighted criterion has shown to come up in a variety of independent ways. This paper is not for pie in the sky desires for no sound. Rather, it attempts to recommend a criterion to use for determining the limits of wind turbine noise. This criterion is based off of the data of four independent sources: (1) CTL, (2) ANSI S12.9 Part 4, (3) Michaud et al. (2016), and (4) a State of Minnesota Department of Commerce survey of criteria set in various foreign countries and provinces. This paper recommends the use of A-weighting and a 24-hour Leq as the metric. 36-38 dB is recommended for the criterion.

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1. INTRODUCTION

A. BACKGROUND

Like most other industries or sources of transportation, noise and noise criteria are a matter of consternation to all sides involved in the siting and development of wind farms. Industry wants the permitted acoustical levels as high as possible, the community wants them as low as possible, and the municipality or county wants to maximize the dollars in their budget. For the past 10 or 15 years there has been an evolution towards developing a metric and criterion for wind turbine noise. Many turbines were built with what turns out to be rather high levels. They were designed with the community level being set at 50 or even 55 dB (A). Gradually, these levels have decreased, but friction between the community groups, the developers of the wind farms, and local government continues to this day.

B. PURPOSE

The purpose of this paper is to explain and evaluate the metric by which the community response to wind turbine noise is gauged and the limits appropriate to that response function. Chapter II deals with selection of the metric, and Chapter III presents the data and methods used to establish criteria and a criterion, based on the metric selected.

C. APPROACH

The approach to the selection of a metric is pragmatic. When looking at the present situation, A-weighting is the only appropriate metric for most noise sources. Based on all that we know, it could well be that C-weighting is preferred, or even Z-weighting or lower would be an improvement. But pragmatically, what is in use today and has corresponding response functions is A-weighting. These issues are dealt with in Chapter II.

In the second and more major part of the paper, various *independent* references and their procedures are used to find data on which to base the selection of a recommended criterion. These data come from four very independent sources. The use of four totally independent sources of data, independent from each other and independent from the issues at hand cannot be stressed enough. For example, the community tolerance level (CTL) was developed based on road traffic and airport noise, totally independent of wind turbine noise (WTN), totally independent of American National Standards Institute (ANSI) S12.9 Part 4, totally independent of the Health Canada study, and totally independent of the Minnesota Department of Commerce study. Similar statements can be made of each of the four sources, and these four sources are equally independent from the parties concerned (industry, community, and local government). They are totally independent of the results from the ANSI S12.9 Part 4 calculation, because these results were developed without having wind turbines mentioned or included in any way, as this was just a general procedure for environmental noise. Any assessment here is certainly independent from the Minnesota Department of Commerce existing criteria levels. The average and extremes of those data are what they are; nothing we do here can influence that. CTL is derived for other sources and other places, and not constructed for WTN, so its application is totally independent from wind turbine noise sources. The Health Canada data are not totally independent of the issues at hand, but the authors argue that the Health Canada data are equally independent for all three parties. In the same test with the same subjects, the Health Canada study finds that there are no health effects that can be found at the resolution that one gets with about 1200 subjects, but that there are substantial annoyance effects with these same subjects in the same study. One finding for industry, one finding for the community. That is, with the same sampling, the same noise measurements, the same noise predictions, the same surveyors, the same survey instrument, the same subjects, one gets half of the results that in some sense support industry, and half of the results that in some sense support the community. At least to this authors' mind, Health

Canada represents an independent government entity not aligned with any of the three parties. The four sources are as follows:

1.data inherent to community tolerance level (CTL);

2.ANSI S12.9 Part 4

3.data from Health Canada, used to establish the equivalency between wind turbine noise and other noise;

4.the Minnesota Department of Commerce

Note: None of the data was developed by these authors and each of the sources is independent from any of the three primary groups involved: community, developer/operator, and local government. Thus, our approach is to present and explain these sets of data or procedures, and to show how they relate to the general method and the criterion that is ultimately selected.

1. CTL provides a one-number assessment of a set of cluster data from an attitudinal survey. Depending on what is held constant, almost any situation can be compared in decibel units of day-night level (DNL). Keeping with current practice, road traffic noise is used as the baseline. The difference in CTL between a data set under study and road traffic noise is the decibel difference between the two CTL values, respectively.
2. ANSI S12.9 Part 4 is directly used to form a small range of levels for potential development of a criterion.
3. Direct use of the Michaud *et al.* data and other similar international data to set a criterion.
4. Data from a State of Minnesota Department of Commerce survey of criteria set in various foreign countries and provinces.

2. SELECTION OF A METRIC

A. DISCUSSION OF WEIGHTING

As is well known, most sources are assessed using A-weighting with perhaps an adjustment for sound character (e.g. tonal or impulsive). A basic version of this assessment metric has been used since at least 1971 when the first version of ISO 1996 (International Organization for Standardization) was approved. The only source for which A-weighting is not used is high-energy impulsive noise, e.g. sound from demolition, open pit mining and quarrying, sonic booms, and noise from military training. For these sources, C-weighted data are collected, and these data are transformed to equivalent A-weighted levels in terms of equal annoyance (ANSI S12-9, ISO 1996-1).

There is no function that relates C-weighted wind turbine noise to an equivalent A-weighted level, nor is there a function that relates Z-weighting to an equivalent A-weighted level. The C-weighting procedure for high-energy impulsive noise took about 25 years to validate and get into use. Correlation between A-weighting and C-weighting in response to turbine noise has been shown, but this does not show that either of the weightings is correct. There is no conversion tool upon which to develop equivalent A-weighted levels. A response function is required. But it can be observed that a high degree of correlation between A- and C-weighting exists; so high that there is virtually no difference between using C-weighting or A-weighting. When one has a class of sources that all have the same spectrum, then the difference between different linear filters that all measure at least some part of the sound will all be highly correlated with one another. The difference between A-weighting and other weightings is that response functions have been created and scrutinized for A-weighting.

A constant, 24-hour A-weighted equivalent level (Leq) computed over the day and night periods, is the recommended metric, and in nearly all cases, the metric of interest is the nighttime Leq resulting from wind farm operations. So, as with aircraft and other noise categories that are dominated by one kind of source, comparisons can be made from one situation to another because the spectral content has not changed from one situation to another. For example, if one is measuring traffic noise, then the Leq for the hour beginning at 1500 measured on Tuesday should be similar to the hour measured at 1500 on Wednesday.

If the appropriate computational procedures are chosen, then one can install a barrier, have a reasonable chance at predicting a reduction, and subsequently produce a meaningful reduction for the community. That is not the situation with wind farm noise. It has been shown that the correlation from one type of wind turbine to another, and from one size to another, results in a set of numbers that properly order different situations because there is no change to the spectrum from one wind turbine to another. But this is not the case if one performs mitigation and predicts the benefit based on A-weighting. A barrier can be built alongside a highway and the reduction can be predicted. The corresponding decrease in community annoyance can also be predicted, at least to a reasonable degree. We cannot make the same statement about wind farm noise.

The reader should be cautioned not to believe that A-weighting is the correct weighting function for wind farm noise assessment. This simply has not been shown. Currently, however, the A-weighted levels assigned to different community responses seem to fit current wind farms in terms of response and level, at least in terms of annoyance based on attitudinal survey data. A-weighting is not chosen because it has been shown scientifically to be better than other metrics. Rather, it is chosen because at the current state of development, to date, no one has shown any metric to be superior. Even if it were available today, it would still take quite a while to gain acceptance for such a metric.

B. METRIC

The choice of a metric is limited. In principle, all of the readily available noise metrics are those built into sound level meters and other similar devices. The non-time integrating metrics are very limited in the data provided. Lmax and Lmin are two non-integrated choices, but it is clear that Lmax may be something that occurs for a short time every once in a while (e.g., once an hour or once a day). In the class of time-integrated metrics, there are three prominent choices: Leq, Ldn, and Lden. These three are not significantly independent; rather, there are very clear and consistent differences among them. Leq 24-hour is predicated on the assumption that wind farm noise emissions from a given turbine throughout the 24-hour day are more or less constant (read ±1 dB). The question is: how far above Leq must the DNL be such that the calculation of Leq during daytime added to (Leq+10) dB at night equals to DNL? The difference between the numerical value for Leq and DNL when the Leq is held constant is about 6-7 dB. A similar number exists for DENL. DNL or DENL provide no additional information as compared to the simpler, constant 24-hour Leq. Were Leq not a constant, and Ld and Ln are not constant, then a more complicated difference between DNL and 24-hour Leq would be required.

3. METHODS AND PROCEDURES BY WHICH A CRITERION FOR WIND TURBINE NOISE CAN BE SELECTED

A. DIFFERENCES IN COMMUNITY TOLERANCE LEVEL (CTL) BETWEEN ROAD TRAFFIC AND WIND TURBINE NOISE

At this point, it is proposed that a relationship between percent highly annoyed and various nighttime Leq levels be established. However, the recent papers by Fidell et al. and Schomer et al. relate percent highly annoyed to DNL. These two papers also introduce the concept of community tolerance level (CTL). This paper will establish the relationship between nighttime Leq, CTL, and DNL for wind turbine noise. Once that is done, we will compare various DNL and CTL levels with wind farm levels. As a part of this comparison, we will include the transformation of CTL or DNL data to nighttime Leq in order to have valid comparisons. First, DNL will be discussed, followed by CTL.

Up until the introduction of CTL, all community attitudinal survey data were analyzed by using linear regression analysis. There was no underlying functional relation. With CTL, it is hypothesized that the community response to environmental noise is similar to the basic human loudness function where loudness is proportional to the independent variable raised to the 0.3 power. Secondly, it is hypothesized

that the functional form of a relationship is a transition function, and for the sake of simplicity, the simplest form of a transition function is used: e^{-v}. It becomes:

$$\%HA = 100 * e^{-1/(10^{\left(\frac{Ldn-Lct+5.306}{10}\right)^{0.3}})} \quad (1)$$

where 5.306 is an arbitrary constant K. The property of K is such that when Ldn=Lct, then Lct corresponds to the 50th percentile for %HA. That is, for purposes of convenience, the value of CTL for a given community is standardized at the midpoint of the exponential function. A CTL value thus corresponds to the DNL value at which half of the people in a community describe themselves as highly annoyed by transportation noise exposure. As Fidell *et al*. (2011) show, the constant 5.306 follows from the definition of CTL as the midpoint of the exponential function. That is, when DNL = CTL, the %HA = 50%. (Definition of CTL at a point other than 50% on the exponential function would merely result in a change to the constant 5.306, with no loss of generality.)

Fidell *et al.* (2011) gives the percent highly annoyed as a function of DNL for all noise caused by airport operations. Schomer *et al.* (2012) does the same for highway and railroad noise. The convention is that all noises are compared to road traffic noise. The difference in the value of K between any source and road traffic yields the numerical difference in dB between the two situations. For example, the CTL for all road traffic is 78 dB and the CTL for all aircraft is 73 dB. So, aircraft is 5 dB less tolerable than road traffic noise. CTL can quantify the difference between any two situations one wants to consider. For example, one could look at the difference between nighttime and daytime, the difference between hilly country and flat country, the difference between urban, suburban, and rural, or the difference between communities on the ocean and those landlocked.

Michaud *et al.* (2016) calculates the CTL for wind turbine noise to be 62 DNL. That is, 16 dB must be added to the DNL of road traffic noise to make it equivalent to that of wind turbine noise. Michaud et al. also calculate the CTL for each of his two study areas, Prince Edward Island and Ontario, independently. In addition, they calculate the CTL for other surveys that provide the necessary data to calculate the CTL (Pedersen et al. 2004, 2007, 2009; Yano et al. 2013). Michaud shows that the CTL for Ontario is very similar to the CTL for Pederson et al., 2004 and Yano et al. 2013. The CTL for PEI is shown to be very similar to the CTL for Pederson et al 2007 and 2009. The CTL for Ontario is about 7.5 dB lower than the CTL for PEI. They also compute the average CTL for windfarms and that is what is used herein.

B.USE THE DIRECT HEALTH CANADA AND THER COMPARABLE INTERNATIONAL SURVEY DATA OF %HA AT VARIOUS TURBINE NOISE LEVELS

This method is the simplest, it says that the %HA at a certain dB(A) is exactly what is measured. There are three data points provided by the Health Canada analysis: the ranges are from [30-35) dB, [35-40) dB, and [40-46) dB. The corresponding %HA are 1%, 10%, and 14%.

In this paper, several primary sources of data are used to develop the functional relationship and select the criteria. Once a DNL is chosen as the metric, the second step is to establish percent highly-annoyed as a function of DNL. This %HA can then be compared to the results from Michaud *et al*. to form a criterion.

C. USE THE S12.9 TO DIRECTLY DEVELOP A CRITERION

ANSI S12.9 Part 4 uses DNL as its primary metric. ANSI S12.9 Part 6 establishes 55 DNL as the criterion for start of impact from noise. Part 4 also establishes the adjustment of 10 dB for quiet rural areas, i.e. the criterion drops to 45 DNL. In terms of a 24-hour A-Leq, this criterion drops to 39 dB. So,

we find 39 dB to be a criterion, independent of the noise source. This derivation never mentions wind turbine noise.

D. USE THE MINNESOTA DEPARTMENT OF COMMERCE FINDINGS

Minnesota, like 29 other states (reference 2 from Haugen 2011), has a state renewable energy objective that calls for "25% of the state's electrical energy to come from renewable sources including wind energy by 2025 (reference 3 from Haugen 2011)." "While many people support wind energy, some have become concerned about possible impacts to their quality of life due to wind turbines, including noise, shadow flicker, and visual impacts…" Because of these concerns surrounding wind power, the state set out to survey a variety of players in the wind energy industry, from many foreign regions and countries. "For this report, a variety of professionals working on renewable energy issues within national and regional governments, wind energy associations, wind energy development companies, and other areas were contacted by email."

The Minnesota findings are shown in Figure 1. This figure shows national and regional wind farm limits in two different kinds of areas: (1) residential and other noise sensitive areas, and (2) all other areas. These are represented in the figure as a solid blue bar for the sensitive areas, and a solid green bar going above the blue for the other areas. Only 3 of the 19 jurisdictions are above 40 dB: Spain, Portugal, and the Netherlands, and the average is 36 dB.

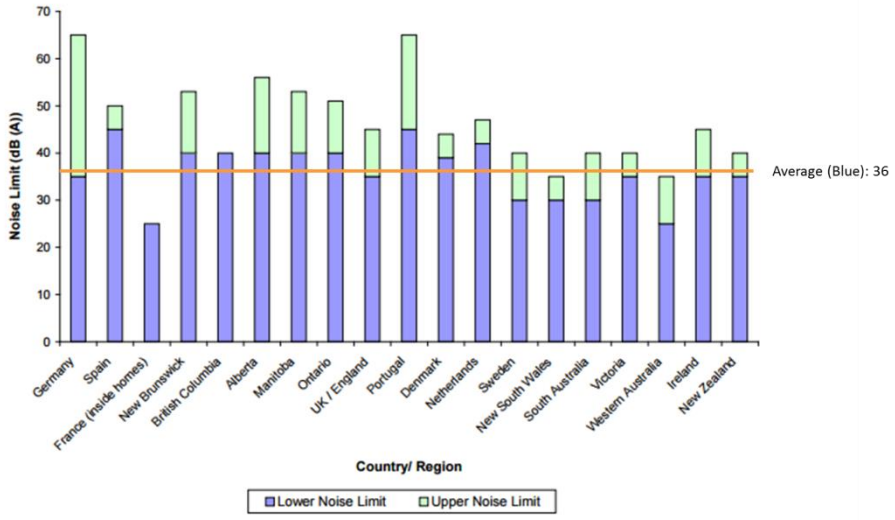

Figure 1: International wind turbine noise limits obtained by the Minnesota Department of Commerce

4. EVALUATION OF CURVES EQUATING DNL TO %HA

In this report, data from six different sources are examined in an attempt to develop a %HA criterion for wind turbine noise (and most other noises): Schultz, the Committee on Hearing, Bioacoustics, and Biomechanics (CHABA), the Federal Interagency Committee on Noise (FICON), CTL (Fidell *et. al.*,

Schomer *et. al.*), Miedema and Oudshoorn (2003), and Miedema and Vos (1997). Schultz, CHABA, and FICON are all based on the Schultz's 1978 synthesis of social surveys on noise annoyance, with the CHABA curve being virtually identical, and FICON being mysteriously low in the relevant DNL interval (60-75 DNL). Miedema and Oudshoorn is an improved version of Miedema and Vos, and along with CTL is used in the current version of ISO 1996-1. Schultz, CHABA, and FICON use data from a combination of aircraft and road traffic noise sources to arrive at their %HA values, whereas CTL, Miedema and Vos, and Miedema and Oudshoorn all make a distinction between aircraft and road traffic. The curve given by Miedema and Vos is shown in the figure for reference as a dashed blue line, but is not included in the analysis that follows because they are two variant data fits to the same data base by the same organization, and using both of them could bias the calculations that follow.

These five sources and their %HA from 50 to 70 DNL in 5 dB increments are shown in Table 1. In this table, Miedema and Oudshoorn and CTL both have separate equations for road traffic and air traffic. CHABA and FICON each use their own single equation for all modes of transportation; planes, trains, and automobiles. Research has conclusively shown that aircraft sound is more annoying than other sound for the same numerical value, which implies that the DNL values Schultz, CHABA, and FICON attribute to a corresponding percentage of high annoyance must be biased high for use with road traffic. And conversely, the %HA for aircraft noise must be biased low. Part A of Figure 2 shows the five functions described for road traffic noise, and Part B shows the five functions described for aircraft noise. From the figures, it would seem that the biased low is a much stronger factor than the biased high. In fact, from the data, one would be tempted to say there is no bias high, but from the logic, this seems to be impossible. As shown in Figure 2A, the Schultz, CHABA, and FICON curves fit somewhat closely to the road traffic curves, but understates the %HA value. For aircraft noise (Figure 2B), %HA values are understated by a very large amount, nominally 15%.

ROAD:					
Group	**M&O**	**CTL**	**CHABA**	**FICON**	**SCHULTZ**
50	3.8	0.7	2.3	1.7	1.3
55	6.6	3.1	4.6	3.3	3.9
60	10.6	8.6	8.7	6.5	8.5
65	16.5	17.6	15.2	12.3	15.2
70	25.1	29.2	24.5	22.1	24.6
AIR:					
Group	**M&O**	**CTL**	**CHABA**	**FICON**	**SCHULTZ**
50	5.3	3.1	2.3	1.7	1.3
55	11	8.6	4.6	3.3	3.9
60	18.6	17.6	8.7	6.5	8.5
65	27.8	29.2	15.2	12.3	15.2
70	38.5	41.9	24.5	22.1	24.6

Table 1: %HA values at different DNL levels for 5 sources

There is no doubt that both Schultz and CHABA represent excellent researchers and excellent organizations. Their results differ from more recent results by Miedema and Oudshoorn, Fidell, and

Schomer. The only conclusion one could come to is that the two databases being analyzed are not the same, and that is known to be the case. The database used by Schultz contained 11 clustering surveys, of which six were aircraft, four were road traffic, and one was railroad. In contrast, the three more recent curves are based on a much larger database. Fidell used 43 aircraft surveys for his work, and Schomer used 39 road traffic surveys and 11 railroad surveys, totaling 93 surveys used to create the CTL method. Miedema and Oudshoorn is based upon a similar quantity of data. A large quantity of the data is used both for CTL and Miedema and Oudshoorn. For a variety of reasons, the authors of this paper will use the methods based on the larger database, Miedema and Oudshoorn, CTL, and CHABA.

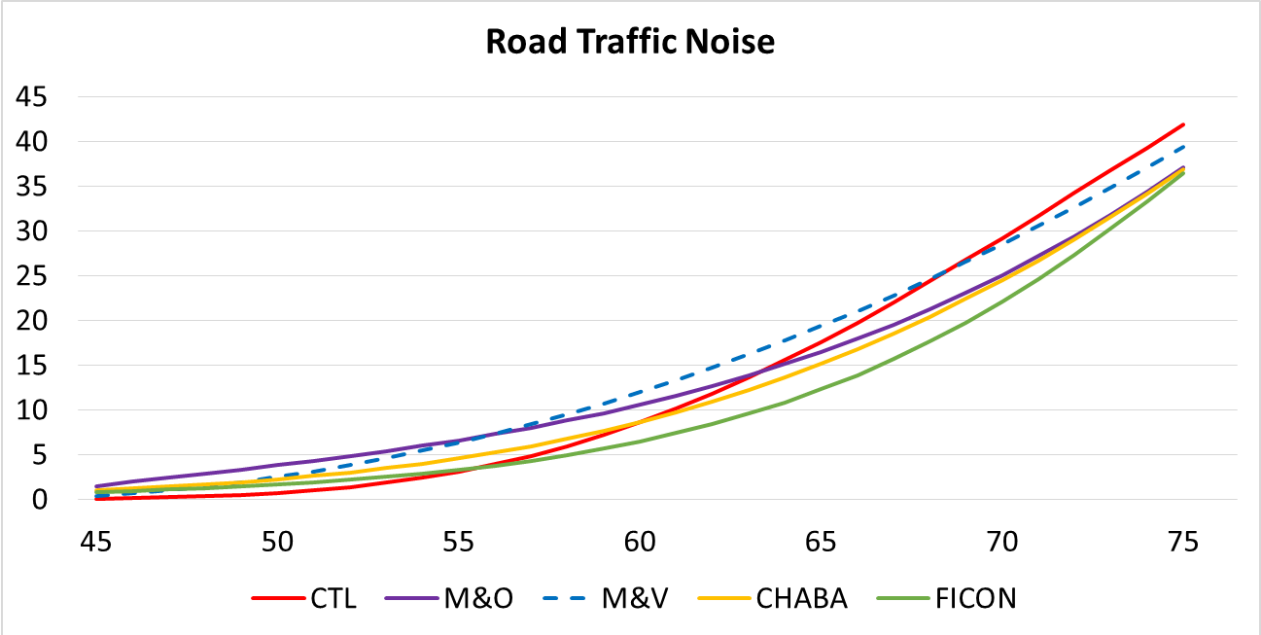

Figure 2A: 5 curves for determining %HA for road traffic noise

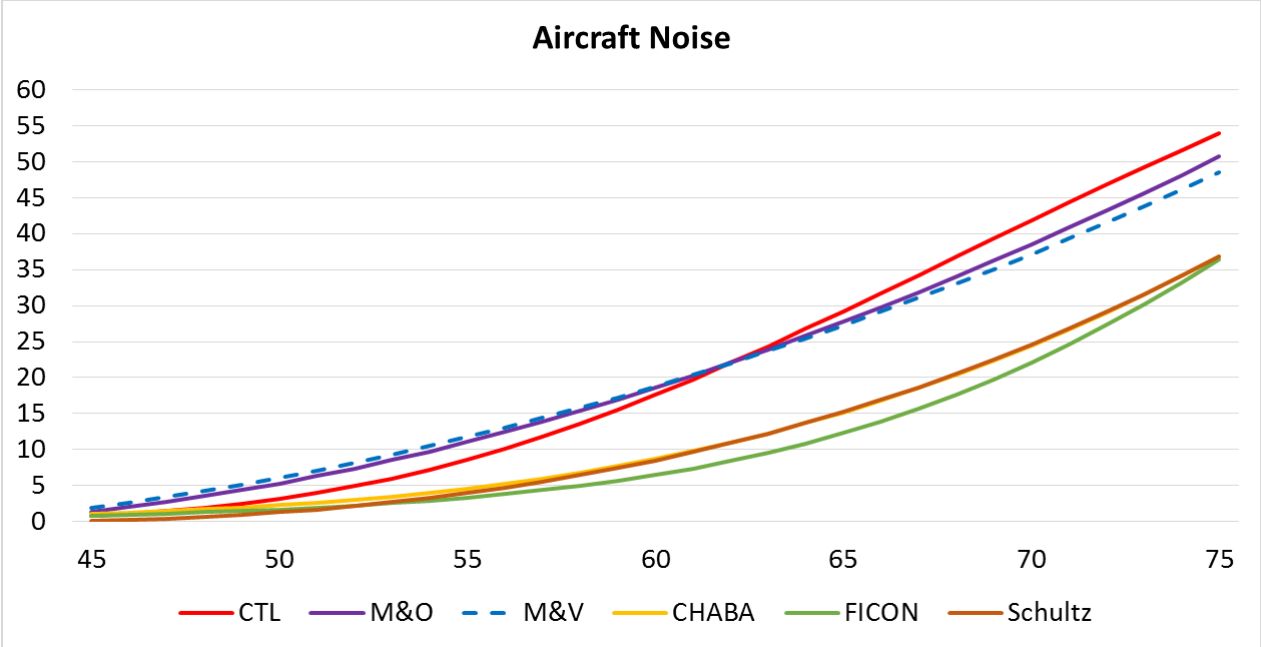

Figure 2B: 6 curves for determining %HA for aircraft noise

5.WHAT IS THE ACCEPTABLE LIMIT FOR PERCENT HIGHLY ANNOYED (%HA)?

A. ESTABLISHING A FUNCTION FOR %HA vs DNL

Since the purpose of this report is to establish data and relations for the selection of a wind turbine noise criterion. In this section, four independent methods are given with which to establish a relation by which to judge wind turbine noise annoyance. During at least the last several years, it has been common to use road traffic noise as the "yardstick" by which other noises are measured. Miedema and Vos (1997), Miedema and Oudshoorn (2003), Fidell *et al.* and Schomer *et al.*, as well as ISO 1996-1 all use road traffic noise for this purpose.

In 2005, Schomer examined the metrics and criterions used by nearly every federal agency and board, by recommendations in national standards, and by international recommendations such as those made by the World Health Organization. These, and multiple other sources agree to 55 DNL as an acceptable criterion for road traffic noise. Therefore, we will use 55 DNL as our intermediate criterion. The term "intermediate" is used because the real issue is annoyance and not decibels. It is very common to relate %HA to decibels, but it is almost always decibels that are measured and not annoyance. For a DNL of 55 dB, 4 different estimates of %HA were found in the literature. CTL equates 55 DNL with about 3% HA, Miedema and Oudshoorn equates 55 DNL with about 7% HA, for road traffic and aircraft noise separately, and CHABA predicts about 5% for a DNL of 55, for both air and road traffic combined. Herein, we will be using the average of these four estimates, which is 5%.

B. CHOOSING A CRITERIA

1. The first method, the method that is dependent on %HA, relates the data from Health Canada to the 5% value established above. Michaud *et al.* (2013) writes that "Consistent with Pedersen et al. (2009), the increase in wind turbine annoyance was clearly evident when moving from [30–35) dB to [35–40) dB, where the prevalence of wind turbine annoyance increased from 1% to 10%. This continued to increase to 13.7% for areas where WTN levels were [40–46] dB." Michaud relates 3 different values for %HA values with 3 corresponding decibel levels: 1%HA is related to 32.5 dB(A), and 10%HA is related to 37.5 dB(A). Therefore, 5%HA would be related to a value between 32.5 and 37.5 dB(A), most likely around 35 dB(A). With this method, a 5%HA criterion is related to 35 dB(A). A more conservative criterion is given by the doubling of the %HA from 5 to 10%. For this second %HA limit, the corresponding dB(A) level is 37.5 dB(A).

2. The second method compares CTL for road traffic noise to CTL for wind turbine noise. The average CTL for road traffic noise (Schomer *et al.* 2012) is 78.3 dB. In comparison, the average CTL for wind turbine noise is 62 dB. So, a 16 dB difference is found between wind turbine noise and the traffic noise "yardstick." To complete this comparison, one must have a value for an acceptable DNL for road traffic noise. Here, a range of DNL is considered: 55-60 dB. Subtracting 16 yields a range of 39-44 dB for wind turbine noise. As per section II-B above, 6-7 dB is subtracted from DNL in order to calculate Leq. This subtraction yields a range of 32-38 dB as a limit for wind turbine noise.

3. A third method to develop a criterion is to directly apply ANSI S12.9 Parts 4 and 5. Part 5 recommends a DNL of 55 dB for residential areas as a limit based on the start of impact. Part 4 recommends a 10 dB

penalty on the limits for quiet rural areas. Most wind farms are built in quiet rural areas, so this penalty is applicable in this case. In a quiet rural area, the DNL limit becomes 45 dB. But this is DNL, to get to Leq we must subtract 6-7 dB, so that the recommendation becomes an Leq of 38-39 dB.

4. Data published by the Minnesota Department of Commerce, shown in Figure 1, give noise limits for sensitive rural areas and non-sensitive areas. As an example of land use designations, wind turbine noise limits in South Australia are based on the highest level applicable between: rural areas at 35 dB(A), non-rural areas at 40 dB(A), or 5 dB(A) above background measured as L90. The average value of the noise limits for sensitive areas given by the Minnesota report is about 36 dB(A).

6. ANALYSIS AND CONCLUSIONS

Four independent data sources are used to create four estimates of an acceptable 24-hour A-weighted Leq criterion for wind turbine noise. Two methods use 5% highly annoyed as the estimated start of impact for a receiving person. The remaining methods examine both adjustments to a recommended DNL indicating start of impact, and an analysis of existing wind turbine noise limits. The four estimates of a criterion are listed below:

1. 5% HA is shown to be a very approximate average to a criterion for %HA. In order to be conservative, the range from 5 to 10% is considered herein. Applying a 5% HA value to the Health Canada data gives a limit between 32.5 dB and 37.5 dB, or about 35 dB(A). Applying a 10% HA value to the Health Canada data gives a limit of 37.5 dB(A) (Michaud *et al.* 2016b).

2. A 16 dB difference is found between the CTL for road traffic noise and WTN, and if the metric is Leq, then the difference between WTN and Leq is another 6-7 dB, for a total of 22-23 dB difference. Comparing the CTL for wind turbine noise to the CTL for road traffic at the lower limit of 55 DNL for road traffic suggests a limit of 32-33 dB(A). Comparing the CTL for wind turbine noise to the CTL for road traffic at the upper limit of 60 DNL for road traffic suggests a limit of 37-38 dB(A).

3. Applying ANSI S12.9 Parts 4 and 6 to determine the level at which impact will start in a quiet, rural area gives a limit of 38-39 dB(A).

4. The average of existing worldwide limits found in the Minnesota Department of Commerce report for sensitive areas is about 36 dB.

As applicable, Table 2 lists the minimum, average, and maximum Leq criteria for wind turbine noise for each of the four methods above:

	Minimum (dB)	Average (dB)	Maximum (dB)
1-%HA		35	37.5
2-CTL	32		38
3-ANSI		38	39
4-MN DoC		36	
AVERAGE	**32**	**36.3**	**38.2**

Table 2: Minimum, average, and maximum Leq criteria

The average of the top-end values is about 38 dB(A) and the average of the middle values is about 36 dB(A). The minimum level, 32 dB, is not emphasized. These four sets of independent data result in criteria recommendations that are remarkably close to one another, lending support to a 24-hour A-weighted Leq wind turbine noise criterion in or around the range of 36-38 dB(A).

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