ACOUSTIC NOISE TESTING

April 12, 2012

Coordinator: Welcome and thank you for standing by. At this time all participants are in a listen-only mode. During the question-and-answer session, please press star 1 on your touch tone phone. Today's conference is being recorded. If you have any objections, you may disconnect at this time. Now I would like to turn the call over to Tony Jimenez, National Renewable Energy Laboratory. Thank you. You may begin.

Tony Jimenez: Hello everybody. This is Tony Jimenez with NREL and this is the last of our pre-conference seminars for the Small Wind Association of Testers conference scheduled for April 24 through 26 in Ithaca, New York. And this webinar will cover the IE61400-11 standard which is basically the standard that covers small and turbine noise testing.

Our presenter today is Arlinda Huskey and she is a supervisor here at the National Renewable Energy laboratory specifically at the National Wind Technology Center and she's worked for NREL since 1995. Her activities include field testing of wind turbines both small and large. She's involved in noise par performance and low testing of wind turbines as well as duration of safety and function testing for small wind turbine.

She is a member of the IEC Power Performance Maintenance Team and Secretary of the IEC Acoustic Maintenance Team. Arlinda is a Supervisor of the Test Projects and Partnerships Team which include certification and field testing. So Arlinda, it's all yours.

Arlinda Huskey: Hi. Good morning or good afternoon depending on where you are. So this is the last and probably the least understood - the acoustic standard. So I've

given this presentation and I've kind of modified it a little bit, but what I'm basically doing here is I'm stepping through the actual standard and talking about the different sections and how they're relevant. And I'll be going through the analysis a little bit slower and I will have an example so hopefully that'll make the analysis process a little bit easier to understand.

So the relevant standard is the 61400-11 and I show a picture of it here. The latest version of it is actually a 2.1 addition and there was an amendment after the 2.0 revision so that was the .1 and it changed the tonality section a little bit. But the main results of the standard include these overall sound power levels, the one-third octave levels, and tonality. And the standard will also give you guidelines about instrumentation and measurement locations and stuff like that.

But as I go through the standard, I'm going to make a note that there's two SPLs that I'm referring here to here. The lower case spl is a sound pressure level and the sound pressure level is the sound at a receptor location. So normally when you're giving overall sound pressure levels, it's usually given with the distance as opposed to what I use the upper case SPL is a Sound Power Level.

The Sound Power Level is usually the sound at a given - it's usually at the source over a given area. In this case, it's a 1 meter squared area and that's considered at the rotor. So it's not given with the distance, it's considered the source and those numbers are usually a lot higher than the sound pressure levels and hopefully we'll be able to point out the differences in the sound pressure levels and the Sound Power Levels as we're going through the standards.

So the first part, it talks about the scope and it generally tells you what the standard is used for and maybe who uses the standard. But generally it's to characterize the noise emissions of a wind turbine and it talks about the different methods or some of the assumptions that are made. So methods appropriate to a noise emissions assessment at locations close to the machine in order to avoid errors due to sound propagation, but far enough away to allow for the finite source size. In that complicated sentence talks about kind of how it's being assessed.

One big point for small turbines when you're going through a standard like this is that the final results whether it's the IEC or AWEA which all kind of are based on the IEC, it allows you to compare different wind turbines despite the size, despite how far you measure from the turbine you will be able to have a measure that will allow you to compare different wind turbines. And this is important for small wind turbines because it's consumers that are trying to compare like you would compare car and miles per gallon. In this case you can compare small wind turbines by estimated power output and sound level comparisons and things like that.

And the other important part of these standards that we've been going through is that it provides methods that will give you a consistent and accurate result so that you have an idea of all these different wind turbines are being tested in the same manner so you can easily compare the numbers. And you should be able if you were to take that - do another test on another turbine in a different situation under different conditions that you would get similar results.

And the last point is this is a guideline for many different types of analyses and in some cases you do not need to go through the entire procedure to get the results that you need. For example, the IEC the main results come out are sound power level, third octaves, and tonality for small wind turbines. And if

you're looking at the AWEA standard, they're only looking at using the sound power results. They don't require you to report the results or do the tonality analysis. In that case you're not using the entire standard, but you're using less or you're just using the sound power methods.

So the second section, it's just references to some of the - it could be equipment such as you're using sound level meters so there's an IEC standard for accuracy groups type 1, type 2, different requirements for meeting certain accuracy requirements of the standard. So there are just references to those. For large wind turbines, you're using power to get back to the wind speed so they refer to the power performance standard, IEC61400-12-1. And then there's also references to IEC standards for filters, frequency, and things like that.

The third section you get into definitions and Section 4 is symbols and units. Section 3 just goes over the definitions and explanations for some of the more important variables. And Section 4 gives the symbols that are used throughout the standard along with the units and sometimes it helpful when you're looking at an equation and you're trying to figure out okay should it be in dB or dBA pressure, is it in (pasquale), (pillow pasquale). So it's usually helpful to go back and figure out when you're trying to apply the equation to what units you should be using.

The Section 5 is an outline of a method so it's just a few paragraphs that talk about the standard and the methods and talks about the outline of how the instruments, equipment, calibration intervals, measurement location, acoustic measurements, and database requirements. The non-acoustic measurements like wind speed, wind direction, the data analysis. There's three sections for sound power level, one-third octave, and narrow band or finality analysis. And then there's reporting requirements in there as well.

So let's jump into Section 6 where they start talking about the instrumentation. So the required acoustic measurements for the standard include overall sound pressure levels, one-third octave levels, and narrow band spectra and this data can be collected by different types of instruments. You can analyze by using different types of instruments like a signal analyzer. In my case, I use software that's on a laptop and then includes all the acoustic analysis tools as well as the recording device.

You can also use hand held instruments like a sound level meter that may plug into a data logger or something like that. And then there are also requirements for the type of instruments you use. There are different accuracy classes. And for IEC standards you need to use type 1 accuracy instruments and filters and they also give a frequency range that you need to use for measurements for the wind turbine noise measurements.

And as you go on, they also talk about a microphone and a pre-amplifier. There are requirements on the size. The diameter can be larger than 13 millimeters. You use the (unintelligible) on a measurement board and then they give requirements on the measurement board. It can be circular with a diameter of at least 1 meter and made with acoustically hard material like plywood. And then there is requirements for thickness.

If you use a larger board, they give a recommendation for a larger board, for soft ground. You can use a metal board that has less thickness. You're also using a wind screen. There is a requirement for a primary microphone wind screen. A wind screen just kind of eliminates the wind noise that you would normally hear from the noise. And when you're listening with your ears you get a lot of the wind noise.

You'll be surprised that when you listen to microphone recordings that have a wind screen how much clearer the wind turbine noise comes in. So there are requirements for the screen. It's one-half (and) (unintelligible) sphere with diameter of 90 millimeters. A lot of these acoustical instrument companies sell these primary wind screens and they usually sell it in a sphere. So to meet this requirement, you can just cut that sphere in half and you would have that wind screen.

And then for high wind speeds, they recommend a secondary microphone wind screen. They are sold and characterized by a few companies, but they can be expensive. It can be somewhere around the $1,000 range. But in the standard they also give specifications to make the secondary wind screen if you can find the type of foam and you can make the wire frame and it kind of gives you ideas of how to make it and also how to characterize it because your secondary wind screen can have effects on different frequency ranges.

So oops, jumped ahead too far. There's also requirements for your acoustical calibrator. An acoustical calibrator basically just puts out calibrated tones to calibrate your acoustic measurements. For example, you got to meet the IEC standard 60942 Class 1. The acoustical calibrator that I have puts out a 94 dB tone at 1 kilohertz. So I will just plug this calibrator into my microphone before my measurements and I'll record it so that later I can go back and calibrate my measurements.

So another requirement is that you have to record your data or be able to play it back. If you're doing your analysis - like if you're doing the sound pressure levels in one path and then you go back and you use your recording to go get third octave levels, you need to have a data recording system. These days a lot of these systems can be written right to hard disk and it does take a lot of space, but otherwise there are other systems like a Dap recording system or

something that's on a tape, things like that. But there are also requirements and there's example in Annex B of how to meet the requirements.

And so in addition to the acoustical instruments, you also have non-acoustical instruments to get the conditions that you're measuring under since you're outside and you can't necessarily control the conditions. You're going to at least keep track of them. So you're going to want to know what the wind speed is and they have accuracy recommendations. And you need to be able to synchronize your non-acoustical measurements with your acoustic data. So that could be two different data acquisition systems and you synchronize it in the end or it could be one data acquisition system, one that collects your sound and your non-acoustic data.

And for large wind turbines, there's also the requirement to measure power because you're going to be using power through the power curve to get wind speed. So there's a requirement for the power (unintelligible). There's also - it's also helpful to have a wind vane or a wind direction sensor. We'll get into the reason for that later on. A camera to take pictures of where you're measuring and what you're measuring, the turbine. You'll need something to measure distance because you'll have to place this microphone board a certain distance from the turbine. You'll need to measure and temperature to get an idea of the conditions that you're measuring - collecting data under.

And also in this section it gives calibration intervals for all your equipment. So they recommend a traceable calibration and there are different intervals for the different pieces of equipment. Your acoustic calibrator is a year. You must get that calibrated annually. And then you can see it can range from two to three years for the rest of the equipment and there are exceptions to that. If you drop your microphone and you suspect that it might not be measuring

correctly, you would send it in for calibration or if its damaged or maybe you need a repair you'll need to get your equipment recalibrated.

So Section 7 goes on to talk about measurement and measurement positions. So for the acoustic measurement position there is one microphone position that is required and there are three optional positions also (given). The downwind position is a reference to (unintelligible) and that is a required position. So typically you have a microphone downwind of your turbine and you would accept data plus or minus 15 degrees from your microphone position because that wind direction can vary. So you can allow some change in the wind, but anything plus or minus 15 degrees out of that we typically would like to make sure that you're getting the wind turbine noise.

And there's a horizontal distance that you must place your microphone from the turbine and that is given by (arnots) and that's the HUB height or the rotor center plus half the rotor diameter. And you would also with this measurement board considering this measurement board is a 1 meter diameter plywood circle, you would want to minimize depending on what type of ground you have you want to minimize any influences of the wind on the board or any extra influences.

So you're trying to make that measurement board as level with the ground as you can get it. So you want to lay it flat on the ground and you want to level the edges or the gaps underneath the board with foil. And this inclination angle is how level your board. The angle between your measurement board and then the line of sight to the turbine and that's the inclination angle and it should be between 25 and 40 degrees. And you want to minimize reflections from any nearby structures. If there's a building or a wall or a hill if you think you might get reflections back on your board, you want to keep your

microphone away from those type of reflecting surfaces. So you would adjust the board to meet these requirements.

And I think I have a picture of a - there we go. There's a picture of a measurement board with the microphone with the primary wind screen. So it says level with the ground and then they kind of push the dirt up against the edges to minimize the edge effects. So if you had a secondary wind screen which is kind of a hemispherical cover, it would just go on top of this. You would keep the primary on there and then you put the secondary on top of it.

So here we show a microphone, the wind screen, the microphone board and you can see the cable going off and that would be connected to a data recorder or sound level meter or a data acquisition system that would analyze and record the data at the same time.

And up at the top on the upper left of the picture, you see a little black block up there. That is an acoustical calibrator that's sitting near the board. They're not very big.

So there's also the measurements for wind speed and wind direction. So you want to get wind speed where the wind flow is not as distorted. So you want to be upwind so you're on the opposite side of your microphone and you're upwind at a height between 10 meters and rotor center, a horizontal defense of 2 to 4 rotor diameters from the rotor center.

And then there's an allowable region for a met tower that's listed in the pictures of the standard. And during tech measurements, the anemometer should not - must not be in the wake of any structures including the turbine and from any given wind direction that you're taking noise measurement. Your anemometer and wind vane should not interfere with each other. And

then there's some other wordage about first (unintelligible) turbines. This is not as important since most turbines usually or likely do not have an (unintelligible).

So here's a picture of how you would have the anemometer, the wind vane, the met tower which is upland of the turbine. And then you would have a microphone board with the microphone downwind of the turbine. So it just kind of gives a picture of kind of what it would look like.

So going on in Section 7 that talks about the acoustic measurements. So you will be getting the following information is recorded for a wind speed range for (unintelligible) wind speed ranges from 6 to 10 meters per second. And you'll be reporting sound power levels for 6, 7, 8, 9, and 10. You'll be reporting one-third octave band levels for 6, 7, 8, 9, and 10 and the same for tonality. Even though it's not required by a (unintelligible) or IEC, if the turbine has any tonality characteristics you would evaluate them for 6, 7, 8, 9, and 10 wind speed ranges.

And then it also gives some guidelines for some optional measurements like directivity, for infrasound, low frequency noise, and impulsivities. The standard does give some -- there is an annex, Annex A I believe or one of the annexes gives some guidance about infrasound low frequency noise and impulsivity but those -- at the time that the standard was written, there wasn't a lot of information or a lot of consistent methods for measuring these quantities. I believe the revision of the standard will have some more updated information.

So for acoustic measurement requirements when you're taking the measurement, you need to calibrate your measurement chain from your microphone back to your data acquisition (unintelligible) or recording device.

You'll need to calibrate that measurement chain at least before and after your measurement session or if you move your microphone because the winds have shifted. If that happens, you'll need to move your microphone and you'll need to re-calibrate.

And what I'm talking about here is when you use your acoustical calibrator to calibrate. I'm not talking about wind speed. This is just your acoustical measurement chain. And you would record data as I mentioned earlier for later analysis and you would emit data as you're recording and sometimes you listen to your data afterwards. You need to take out the data with interruptions in the background such as cars, and planes, and sometimes there is - right now on our site we have birds and we have a train that's nearby. Sometimes we have construction sounds like when one of these vehicles is backing up, you'll hear that beeping and we'll eliminate that data from our valid data set.

And you need to collect two different types of data under similar conditions and similar conditions, I mean similar wind speeds. You want to kind of - you're going to be taking acoustical data when your turbine is running and also when it's not running. When it's running, I'm calling that turbine data and when your turbine is not running I'm calling that background data. You will correct your turbine data with your background data just to quantify exactly just what your turbine is - the noise of the turbine.

And for small wind turbines, you want to really cover as broad a range of wind speeds because for wind turbines their noise - they more typically get noisy when they're trying to limit rotor speed or power. So it may be above 10 meters per second so you wouldn't want to try and collect data above the 10 meter per second range if that's where it gets noisiest.

So the requirements and there's a lot of text here, but basically for sound pressure levels you're getting at least 31-minute average wind speed or a measurement with wind speed when the turbine is operating. The AWEA modification you need 10 seconds averages. And so you need 30 minutes overall with the turbine running and with the turbine stopped, so turbine and background and you need three measurements per wind speed (band). When you're using 10-second averages for statistical purposes, it's usually good to get at least 10 points for wind speed (band). And then you would also need 30 minutes of background covering the same conditions as the turbine measurements.

And usually we are driven by what you need for the sound pressure level because the same data if you have it recorded or you can analyze it at the same time, you will also get the same -- the one-third octave levels -- you'll get it from that data and the same for the narrow band. So if you cover your sound - if you get your sound pressure level requirements, you have your one-third octave levels and your narrow band requirements required. But for one-third octave levels, you need at least three spectra for each wind speed then and then you'll need to cover center frequencies from 50 hertz to 10 kilohertz. And again, you're going to have background for one-third octave levels and then for narrow band you need 2 minutes per wind speed (band).

For non-acoustic measurements, you've got wind speed and the IEC standard is written for any size of turbine and they have a preferred method of getting the wind speed through the power curve. So you're measuring power, you're looking at the power curve, and then you're driving wind speed out of that. But for small wind turbines this does not always work. For large wind turbines, the noise is highly correlated with the power coming out of the turbine. But that is not always the case for small wind turbines.

For small wind turbines, we like to determine the wind speed with an anemometer so you're directly measuring it. And you adjust that wind speed to these reference conditions so that would be 10 meters height and a reference roughness length of .05. And they give you a table in the standards to estimate your (roughness) kind of depends on the type of terrain that you have whether it's, you know, water or farm or trees, things like that. And you would collect your wind speed and you average them over the same period as the acoustic measurements. So you'll get wind speed acoustic data pairs.

You'll also be measuring the wind direction. So the point of measuring wind direction is to make sure that you're getting -- that your acoustic measurements are being made downwind when the turbine -- when the microphone is downwind of the turbine and you're going to estimate that using a wind direction measurement. So wind direction measurements must be within 15 degrees of the (nasel asmith) position with respect to upwind and these are also (arithmetically) averaged over the same period as the acoustic measurements. So the idea is if you have your wind turbine position that would be the best measurement. But again we're talking about small wind turbines so we're better off using wind direction wind vane to measure wind direction and you just want to make sure that you're getting the noise that you're using - that you're measuring is downwind of the turbine.

And there are other non-acoustic measurements. Air temperature and pressure should be measured and recorded at least every two hours. Optionally you can also use turbulence and that's discussed in Annex C. And then there are also a couple of other measurements. Rotor speed and pitch angle are recommended for small wind turbine as well. Small wind turbines don't necessarily have pitch angle and if they did, it's usually passive pitch so it's not easy to collect. But rotor speed is usually a valuable measurement for small wind turbines.

For small wind turbines the noise is usually well-correlated with the rotor speed.

So Section 8 gets into the analysis. So for wind speed - but what I'm going to be doing is I'm going to be covering kind of the equations that are in the standard and maybe the order of the standard doesn't necessarily make sense. So we'll be talking about the equations and what they mean and then I'll cover some examples that use these equations to hopefully make them a little bit clearer. So for wind speed when you're measuring wind speed, I had mentioned that you're taking the wind speed back to this reference.

In this case you're taking it back to 10 meters. So if you're measuring at 30 meters or something above 10 meters this is an equation to take your wind speed from a higher altitude back down to 10 meters and this is using a reference roughness (length). The roughness length is at your site. The rotor center height of the test turbines, a reference height of 10 meters, and where your anemometer height is because your rotor center and your anemometer height be different. And the roughness length at your site can be calculated, but that would require extra measurements or you can estimate it using Table 1 in the standard.

And as I mentioned also that your turbine noise levels will be (corrected) for background. So here's the equation for correcting backgrounds from turbine levels. So what you have is you have your measurements of the L plus S plus (unintelligible) are your turbine measurements when your turbine is operating and your have L (unintelligible) which is your background levels. And so there's some considerations when you're using this equation.

So in order to make a good background correction, your turbine levels and your background levels should be separated by 6 dBs and it's a good

background correction when you have that separation. If your separation is between 3 and 6 dBs then you use the standard correction of 1.3 dBs and you would mark this value with an asterisk and these values would not be used - they cannot be used for sound power level calculation.

If the difference between your turbine and background is less than 3 dBs, you cannot report because your turbine noise would be considered less than background. So you're not able to characterize the turbines noise because it might blend in or the background might be too loud and you aren't able to characterize the turbine alone and that happens sometimes. It may not happen through the entire 6 to 10-meter per second wind speed range, but sometimes it does happen.

So once you get this corrected sound pressure level, you would go on and you would calculate your sound power level. So you would have these sound pressure level wind speed pairs and you have it for at least a range of 6 to 10 meters per second for that wind speed range. And the IEC for large wind turbines the preferred method is to fit a regression through that.

But for small wind turbines, if you're using the AWEA standard, you would (band) the data into 1 meter per second (bands) and you would at least want one point - in your (band) you would at least want 1 point on both sides of the integer wind speed. And then you would (band) the data, you would average the data, you would average the wind speed, you would average the sound pressure levels and then you would get these (unintelligible) levels by interpolating or extrapolating between the (bands) to get the center integer value.

This is done for turbine noise and background and then you would background correct to get the integer value. And using those integer values,

you would calculate the appearance on power levels for each integer wind speed using the equation here.

So as I mentioned early in the presentation that some pressure levels are given at a distance. So in this case you're taking that sound pressure level at a distance and you're converting it with sound power level which is basically at the source for a 1 meter squared area and this is the equation to do that.

So that was kind of a - that I think alone is very confusing and how to apply these equations. I'm hoping - I've got an example here or two to show how these equations are used. So let's look at some actual data that's been taken and how the equations were applied. So what I'm covering here sound pressure levels, the wind speed, and getting to sound power levels. So this would be Sections 8.1 through 8.3 in the standard.

So here's some data that was collected and I'll say this is turbine data. And so you get your wind speed this is at whatever height it's measured at and this is your first look at the data. So you've got wind speed, sound pressure level pairs here and you can see there's a trend here. It's kind of flat and then there's a float to the curve if you were to fit a curve in there, but there are some points that are kind of above and would you consider those outliers and you could.

What I would basically do to find that is I would listen to the data and I would see if there was an airplane going by, if there was a car, maybe I was walking out to calibrate my microphone and I can hear myself walking through and putting the microphone on. If there was any type of interruptions like that, I would eliminate that data.

But here is - down below, you can see that there's a table here and this is kind of what my data looks like. So I've got a time, I've got power -- you can see these are background measurements -- I've got measurements of rotor speed, temperature, wind speed, and meters per second, pressure, wind direction. Availability is usually turbine status if we have it. LAQ are the sound pressure levels and wind direction. That's a column to make sure that my wind direction is plus or minus 15 of the microphone, the measurement board position or the microphone position. And then I have a column that usually tells me whether I'm making turbine measurements or background measurements.

So I usually go through my acoustical data -- my sound data -- and I'll listen to it and I'll listen for interrupting noises: cars, other turbines, airplanes if I'm calibrating or transitions. Maybe the turbine is going from operating to - its running and then its not running, things like that. And then I'm looking for wind direction outside of that plus or minus 15 degrees so I'll use my wind direction for that and I'll plot sound pressure levels versus wind speed or power or rotor speed and I'm looking for those outliers. And if I see something that's kind of outside the trend sometimes I'll go back and re-listen to it if I can't eliminate it. If there wasn't an interruption, I'm trying to figure out what's going on there. Maybe it is real. Maybe the turbine was just going through, you know, there's some extra aerodynamic noise. Maybe it was real, but I need a real solid reason to take it out not just - I won't eliminate it just because it looks like an outlier.

So here is the (banding) and averaging. So here I've got an example over on the right. Again this is kind of data that covers several - it's not just one wind speed (band), but I was just trying to give an idea of how you would average sound pressure levels that's not (arithmetically) average. In this case, its based on power so it's an energy average. So here I give an equation how to average

sound pressure level and on the right you can see I've got wind speed, sound pressure pairs, data points, and down below the wind speed you can see that I averaged the wind speed (arithmetically). But for the sound measurement, you can see that I do the 10 to the .1 times the sound pressure level and then you would sum that. You would divide by the number of points and then you would take the logs and then multiply that by 10.

So the average of all those sound pressure levels that you see above would be 47.8 dBs and the average of the wind speed which I really want to make that distinction that you're doing two different types of averages. For the wind speed you're doing an (arithmetic) average and for the sound pressure levels you're doing an energy average. And so once you get your points within (unintelligible) and the (arithmetic) average, the wind speeds, you energy average the sound pressure level so you would have (band) averages and you have to get to the integer wind speed.

So in that case what we would do is to interpolate or extrapolate at the (bands) if needed to get those integer values. So for the -- let's see, you're extrapolating using the 6 and 7 meter per second wind speed (band) to get the (band) center at 6. Since we don't have the 5, we cannot interpolate so to get the 6 you need to take the 6 and the 7 (wind bands) and extrapolate to get 6. And to get the 7 integer value, the value at 7 you would interpolate between 6 and 7 and you're interpolating using the wind speed and the sound pressure levels. And to get the 8 and 9 integer values, you're interpolating between the 8 and 9 wind speed (bands) since those integer values fall between the 8 and 9 (bands). And you're interpolating between 9 and 10 to get the (band) center at 10 meters per second. And you would do this for your turbine levels and background level. So once you get done interpolating and extrapolating, you should have integer values for wind speed and sound pressure levels at 6, 7, 8, 9, 10 meters per second.

And using those turbine and background levels, this is when you would correct for background for those integer levels. And again what comes into play is the separation. You also have to look at the separation between your turbine and background levels and you need that 6 dB separation to use the equation. And I show an example here. You can see that I have (band) for 6, 7, 8, 9, 10. I got my sound pressure levels for the turbines levels and then I got sound pressure levels for the background. And way over on the right you can see the differences between the two. And then you've got the background corrected values.

And if you see for the 7-meter per second wind speed (band), there was a difference between the turbine and the background that was less than 6. So in this case I used the standard correction of 1. -- I subtracted 1.3 and I got to my background corrected levels, but I would not be able to use that value -- I would not be able to report any sound power level for that wind speed then because the background separation was not there. I would only be able to report sound power levels for 6, 8, 9, 10 and not 7. And then once you get your background corrected levels, you would calculate your apparent sound power levels using this equation.

So for this example we're using the same data as before as in the previous slide. We've got background corrective levels for 6, 8, 9, and 10 and I give the distance between so the (slant) distance -- the R which is the distance between the microphone position and the rotor center -- we calculated that to be 35.1 meters and the reference area is the 1 meter per second, the (S knot). And using the equation, you can see that for our background corrected sound pressure levels that we're in the 40s, mid-40s to mid-50s and those are sound pressure levels that are about 35 meters from the rotor center. Once you go to the source, you can see that they go up by a considerable amount.

So the sound power level for that turbine would be 82 to 90 dBAs and they look like big numbers. But if you have the sound power levels for a turbine, you can take those sound power levels and you can take them to any distance that you need to take them to. So some of these regulations for permitting and things like that for small wind turbines sometimes you need to calculate the sound pressure level at a receptor distance, maybe a neighbor's house or at a fence line or at some distance from the turbine. This is where you can take the sound power levels and take that distance and you can go back to a distance and get the sound pressure levels. So that was kind of giving some examples of how to take the wind speed down to 10 meters height and how to take your sound pressure levels and get them to sound power levels.

So now we're going to one-third octaves, Section 8.4 and procedure for this is similar to your using some of the similar concepts for sound pressure levels that we did a moment ago. The concepts are the same. You're (banding) your - in this case you've got a several sound pressure levels for different frequency ranges. That's basically what a third octave spectra is and you can see an example below.

So we've got a spectra for a turbine point and you can see the center frequency (band) is 20, 25, 31-1/2, 40 and your sound pressure levels are right below that. And you've got -- what you're doing is you're (banding) them again and your (banding) at least -- you're taking at least three of those points. You're taking the three points closest to that integer that were measured closest to the integer wind speed and you would average the wind speed. You would energy average the third octave bands and then you would have a spectra for 6 meters per second, you would have a third octave spectra for 7, 8, 9, and 10 and you would again interpolate or extrapolate to get the integer values.

And then you would do that for your turbine level, you would do that for your background levels again and then you would background correct and in this case you would leave your one-third octave spectra. You would not take that to sound power levels. You just need to get your spectra for the wind speed centers.

And here again you're going to - in order to use the background corrections equation, you need the 6 dB separation. If you -- there is again a -- in this case there is another standard correction for differences that are between 3 and 6. You would subtract the standard correction was 1.3, but if the separation between turbine and background points is less than 3 you can't correct for that because you don't know if your - you can't distinguish background, the turbine from the background. I wanted to make a note that there can be negative numbers. There will be bands where the background levels are greater than the turbine levels. If you see that kind of information, that kind of data that's fine and it happens.

So here's an example of after the - this would be for several (bands). So you can see for some (bands), I'm not reporting any levels for the lower frequency bands. But once you get into the mid-ranges, you're reporting (unintelligible) and then up in the higher frequency ranges again you're not reporting levels because either it just maybe your background levels were higher than your turbine levels or you didn't have the separation required and you wouldn't be reporting those levels.

So the last piece is the tonality or narrow band analysis, Section 8.5 in the standard. In this case again you're taking the same data that you've been using and you're taking the two minutes of data that are closest. For a third octave, you are using the three minutes closest to the energy wind speed. In this case

you're taking two minutes. And what you do with those two minutes is you analyze it once again in a different way. You're getting the FFT spectra which is just breaking that third octave spectra into finer resolution and you're looking for tones in this case.

So third octave spectra are typically used for propagation, you can use that in propagation models. Tonality again is characterizing the wind turbine noise. The tone in some cases can be much more annoying than the overall sound pressure levels. If there is a whistle or, you know, a whistle from the blades -- some aerodynamic whistling -- that maybe more annoying even if the turbine is really quiet.

So what you're doing here is you're taking - you're doing FFT spectra on two minutes of data that are closest to the integer wind speed. And again you're doing this for turbine and background, but it's a little bit different here. So for the turbine data, you're splitting those minutes into 10 seconds and you're doing - you'll have 12 10-second periods for that 2-minute and for each of those 10 seconds pieces of those 2 minutes you're doing an FFT spectra. And your background spectra, you have 2 minutes. You're doing an FFT of those individual minutes and then you would average them together. But the intensive part of this analysis is on the turbine data.

So you're going to have 12 FFT spectra for turbine data for every wind speed (band) and what you're looking for is you're looking for possible tones. So for each -- I'm going to go through the analysis for one of these 10-second spectra -- so for each of these spectra, you're doing the following: You're going to determine the critical (bandwidth) - oh actually you're going to identify possible tones and let's look at what's considered a possible tone.

So technically a tone is a peak in your spectra. So here's an FFT spectra of a 10-second data point of a 10-second recording. So technically a possible tone is the peak (unintelligible) adjacent lines with lower amplitudes. So if you were to consider that technical definition, you have several possible tones in here. But what -- I have some -- there's some automated analysis packages out there that you can either do this manually or you can do some automated - there's some automated software out there.

So I kind of highlighted one of the larger tones. So this is a tone that would probably after on all the analyzing, it would come out as a tone. But there are many other possible tones in that spectra. So once you find a possible tone, you're going to go back and you're going to look at a frequency (band) just around that possible tone and you're going to call this the - you're going to look at the (bandwidth) and it's called the critical bandwidth around this tone and your tone is centered in this range or frequencies around it and that's called the critical bandwidth.

And within that critical band you're going to classify each frequency line within that critical band and you're going to classify them as tones or masking or neither. And from that critical band, you're going to determine a tone level and you're going to determine the masking levels. A masking level is in order for that tone to be audible or to be determined a real tone it needs to stand out from its masking level enough to be considered. So in this critical band you're also going to determine the masking levels and you're going to correct for background and determine the tonality. And the tonality is basically that difference between the tone level and the masking level. And if it stands out enough from the masking level, you're going to determine whether it's reportable or audible.

So if you find a possible tone, in this case we're looking at if you look over on the right here's part of an FFT spectra. This is a critical band and its centered around the value at 249 hertz and you have an SPL of 45.44. So that's the level where the possible tone is at. So this is the critical band around that possible tone and you're going to calculate the critical bandwidth. So if our tone is at 249, we would put it back into this equation and you would find that the critical bandwidth as calculated is 104.43 hertz. And you want to center that critical bandwidth around the peak.

For this example if you're centering it around 249 hertz, your critical bandwidth would be from 196.8 to 301.2 hertz. But that won't - you don't have that type of resolution in your spectra. So how you would center this around that peak is not - is (specifically) dealt with the standards. But for our purpose, we're going to define. As long as you define that critical bandwidth and for our purposes the critical bandwidth that we're using is from 102 hertz to 300 hertz. So for our purposes a critical is 102 hertz so that's going to cover from 198 to 300 hertz and that's dealing with the type of resolution that we have for our spectra.

So one of the first steps is to calculate L70% for classification. So there's a procedure in the standard and I'm not - and this is detailed in Section 8.5 and there's a section called classification (unintelligible) and this is what I'm going through right now. So within each critical band every spectral line that you see down below every one of those bars is considered a spectral line and we will classify each line as tone, masking, or neither. But either the line is going to count as a tone or it's going to be part of the masking or it's somewhere in between and we're not going to consider it at all. So the calculate the L70% level, you're going to take the energy average of 70% of spectral lines in the critical band with the lowest sound pressure levels.

So what I typically do is I have a little macro for this and I would sort it and I would figure out the lowest 70% with the lowest 70% or the lowest amplitude levels and then I would take that energy average. And I had shown you earlier when we were doing another example how to take the energy average. And here again it shows you on the right which lines would be considered part of that L70 and the energy average. It shows you another example of how to do an energy average.

So for this example our L70% is 33.13 and from your L70%, you're going to calculate this (criterion) level, L70% plus 6 dBA. So that number is 39.13 and then we're going to take that number and this is what will allow us to classify our masking lines. So any of our lines that is less than that L70% plus 6 dB will be classified as masking. So if you look on the right any of those SPLs that are below 39.13. So if you look at all the SPLs in the second column any ones that are below 39.13 are classified as masking. So then you would calculate the energy average of all your masking lines and that in the standard is (LPN) average. And here you see the energy average of those lines again which ends up to be 30.11. So we have classified more than half of our lines if you look at the plots and we still have those red lines that we have left to classify in that critical band.

So now we're going to classify our tonal lines. A line is classified as a tone if its above the LPN av plus 6 dBA which is 36.11 dBA. So that will take our peak which was at 249. That'll definitely classify that one as a tonal line. And then where there are several lines classified as tone, you will look at the line having - you will look at your peak, the line having the greatest level and then the adjacent lines to that peak will only be classified as tone if their levels are within 10 dBA. And in this case it looks like most all of those lines -- all the orange lines -- are classified as tone. So it looks like we've got all of our lines classified.

But there are times when it doesn't meet either of the criteria. So if one of these orange lines fell below that or fell outside - was more than 10 dBs of the peak level, but it wasn't classified as masking those lines would be classified as neither and they wouldn't be considered in the analysis. But for our example all the lines were classified as either tones or masking.

So how you would determine the tone level. So you would consider the sound partial levels of the tone which is what is called LPT is determined by energy summing all the spectral lines classified as tone. So in the past we've been doing energy averaging. In this case, we're energy summing so here's the equation for energy summing. So over on the right, we see all the lines that are classified as tones. We take all those levels and we would take the sum in this case. And then the standard also says that if you have more than two lines classified as tones, then you need to do a correction for the (unintelligible) window that was used and you would divide the energy sum by 1.5. You can see in our example on the right that we do all the summing and we divide that by 1.5 so we get a tone level, an LPT of 51.88 and then we do a correction for the background.

Okay. Way back in the beginning of this section, I talked about the 2-minute background spectrum that you had 2 minutes of background, you would take the same critical band from your background and you consider that as masking. You would look at the same critical band and you would want to make sure that the tone that you're analyzing does not originate from that background. You want to make sure that the tone that you're analyzing is only shows up when the turbine's running.

So that's one check is that you make sure that your tone does not originate from background. If it does not, then you calculate the background noise level

by taking the energy sum of that same critical band. And if that difference is - you would do a background correction if that difference is more than 6 dBA. Otherwise if it's less than 6 dBA, you're saying that your tone is influenced by background. So you can't trust that there is really something there. But otherwise if it's greater - if that difference is more than 6 dBA, then you would correct your masking level not your tone level just your masking level with the background level.

So in this case here's our background - the spectrum from our background. The same critical band and we do the energy average and that comes up to 23.03 and our masking level - our LPN av from our turbine levels was 30.11, you would do that background correction. So then you get a masking level corrected by background, your LPN corrected of 23.03. So right now you're got two main numbers. You've got your corrected masking level and you've got your tone level. Then you would also another calculation to get your masking level. Your final masking level -- your LPN -- you would do a correction to it.

So here you're doing a correction using the critical bandwidth which we had determined earlier which was 102 hertz and then you've got this effective noise bandwidth which in this case is 1.5 times the resolution. In our case that resolution was 3 and so our effective noise bandwidth ends up being 4.5 hertz and this equation to get LPN has taken from the standard. So our masking Level turns out to be 36.58 dBA. And that allows you once you get your masking level, you've got your tone level, you get to determine your tonality. So the tonality is the difference between the masking level and the tone level and that (unintelligible) is Delta LTN. So Delta LTN is your LPT, your tone level minus your LPN, your masking level. For the one critical band that we analyzed our tonality turns out to be 15.3.

So for our one critical band tonality was 15.3 and so this was one for 10-second spectrum, one critical band from that spectrum and you will do 12 of them. You may be doing 12 of them because we have 12 spectra from the 2 minutes and you will get 12 Delta LTNs, 12 tonalities from each spectrum. But sometimes one of those 12 will not have a tone. So there is an equation here that gives you a (filler) (unintelligible) so in the end you will get tonality for each of those 12 spectra and you're going to energy average those to 1 what we call Delta LK. And for each of these Delta LKs, a frequency dependent correction must be applied to compensate for the response of the human errors to tones of different frequencies.

So there's this audibility (criterion) that is used to compensate for - to determine whether a human person would be able to hear this tone. So there's this the tonal audibility, the Delta LK is the Delta LK minus LA. The LA (unintelligible) is the audibility criterion and so for our final value our Delta LK we're going to subtract the audibility criterion for that frequency and if that difference is greater than minus 3, it's considered that that tone would be audible to humans and since it's considered to be audible that tone would be reportable. For anything below that, you're not to report it. And the standard kind of tells you what quantities. It'll tell you to - it'll ask for your masking levels and your tone levels and for all 12 of your spectra.

So that was like - the noise standard can be confusing and I think it's probably because of the analysis methods that I think people could have difficulty with and I tried my best here to give an example and show the use of some of the equations and how to apply them. But as always, I know there are questions out there. I know some people can get to a certain point and then they get a little stuck or confused and just give me a call. I've been through this analysis a few times. But basically that's it. Tony?

Tony Jimenez: All right. Well thank you for that very comprehensive look at how to go through it. At this point we'll open it up for questions.

Coordinator: Thank you. We will now begin the question-and-answer session. If you'd like to ask a question, please press star 1. You'll be prompted to record your name. To withdraw your request, please press star 2. One moment please while we wait for the first question. And again if you do have a question, please press star 1. I show no questions.

Tony Jimenez: All right. Well in that case we're done and I want to thank our audience for joining this morning or this afternoon depending on where you're at. I guess it's afternoon for us here now. And again I want to thank you Arlinda for taking the time to put the presentation together and to give it for us. And like all the previous pre-conference webinars this one will be posted on the (Wind Power America) website so you can look at it again at your leisure. Thanks.

Coordinator: This concludes today's conference call. Thank you for participating. You may disconnect at this time.

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