Stetson II Wind Project
Sound Testing Protocol (Original Issue March 15, 2010)
Protocol Details & Calculation Methods
September 13, 2010
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The Sound Testing Protocol for Stetson II Wind Project was developed in coordination with staff at the Land Use Regulation Commission (LURC) and the Maine Department of Environmental Protection (DEP) and submitted to LURC on March 15, 2010 for review and approval. The Protocol establishes criteria for sound level testing of wind turbine operations at Stetson II Wind including instrumentation, site and weather conditions, meteorological data, and sound level measurement reports. The Protocol states "Prior to initiating sound level compliance testing, Stetson II will provide detailed procedures and sample calculations to LURC to be used for assessment of the 5 dBA penalty for the presence of short duration repetitive and tonal sounds as set forth in Maine DEP Chapter 375.10." The following provides details for assessing penalties for short duration repetitive and tonal sounds.

Penalties for Tonal and Short Duration Repetitive Sounds

Maine DEP Chapter 375.10 applies a 5 dBA penalty to certain characteristic sounds that are considered to be more annoying than steady-state broadband sound. This penalty is added to the measured sound levels for these types of sounds and the overall equivalent sound level is re-calculated before it is compared to the applicable sound level limits. The following provides specific details and sample calculations on how to apply the Maine DEP short duration repetitive and tonal sound penalties. Based on testing of other wind turbine projects, occurrences of these types of sounds are not expected to result in significant penalties or adjustments to measured sound levels. An objective of operations testing and analysis of measurement results is to verify this expectation.

Short Duration Repetitive Sounds

The purpose of the short duration repetitive (SDR) sound assessment is to determine the total duration and equivalent sound level (L_{Aeq}) of all SDR events for each 10-minute test period. The Protocol requires reporting of sound level and meteorological data for twelve, 10-minute test periods that meet the specified operating, site and weather conditions. Once the L_{Aeq} of the SDR events is determined, the +5 dBA "penalty" is applied to total duration of SDR events for each test period to calculate the adjusted 10-minute L_{Aeq} for evaluation of compliance.

Rotation of wind turbine blades produces a characteristic swishing or thumping on the down-stroke of each rotor blade, which briefly increases sound output. The change in sound levels that occurs is known as "amplitude modulation". At full rpm of the GE 1.5 sle wind turbine, the down-stroke of a rotor blade occurs at a rate of approximately once per second. Figure 1 presents a sampling of sound level measurements that shows amplitude modulation cycle that occurs approximately once per second. This data was developed for the purposes of establishing calculation details and is not from actual wind turbine measurements.

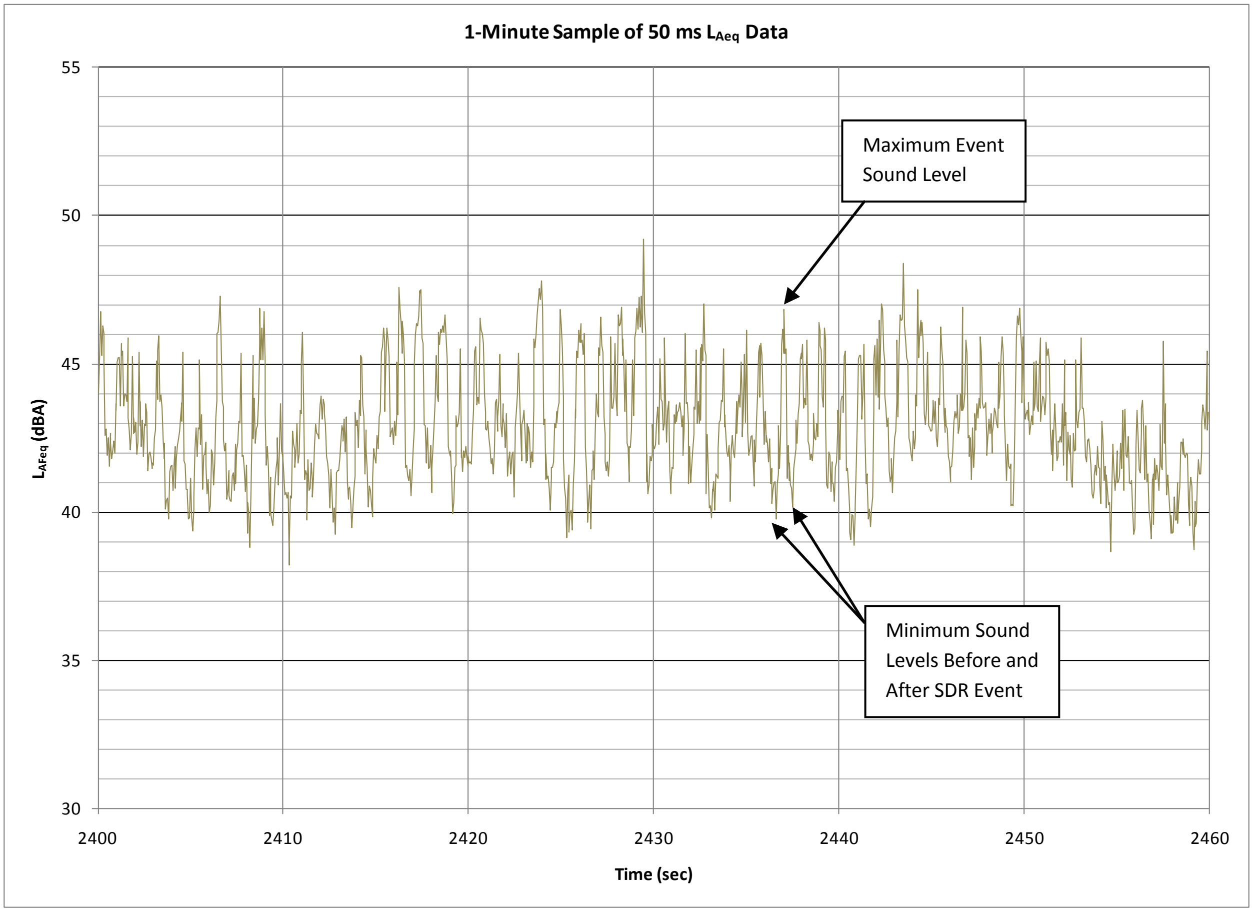


Figure 1. Sound Level Measurements of Amplitude Modulation

Maine DEP Chapter 375.10 applies a 5 dBA penalty for "short duration repetitive sounds" which are defined as:

> "A sequence of repetitive sounds which occur more than once within an hour, each clearly discernible as an event and causing an increase in the sound level of at least 6 dBA on the fast meter response above the sound level observed immediately before and after the event, each typically less than ten seconds in duration, and which are inherent to the process or operation of the development and are foreseeable." (ref. Maine DEP Chapter 375.10.G(19)).

To determine the presence of SDR sound events, the Sound Testing Protocol requires measurement of A-weighted sound levels at an interval of 50 milliseconds (0.05 seconds) or less using a fast time response, i.e. 125 ms. The amplitude of an SDR event is the highest measured 50 ms sound levels during the event minus the average of the minimum sound levels measured immediately before and after the event. Sound level fluctuations from wind turbines qualify as SDR sound events when the amplitude or increase in sound levels during the event is 6 dBA or more. For the example annotated in Figure 1, the sound level increases approximately 7 dBA between the minima before and after the event. In this case, a 5 dBA penalty would be applied to the measured sound levels of the SDR sound event.

The following graph (Figure 2) presents a 10-second sample period of 50 ms sound level measurements to demonstrate the procedure for determining the amplitude and duration of SDR events. Individual 50 ms measurements are indicated as marker symbols on the graph to show the number of SDR events that occurred during the 10-second period. The minimum sound level before and after each event and average minima are also indicated by labels. Event duration is the time in seconds extending from the minima immediately before and after the maximum sound level of the SDR event. The first SDR event occurs when the measured sound level reaches 47.0 dBA, or 6 dBA above the average minima of 41.0 dBA. There were five SDR events during the 10-second sample period as indicated in Figure 2.

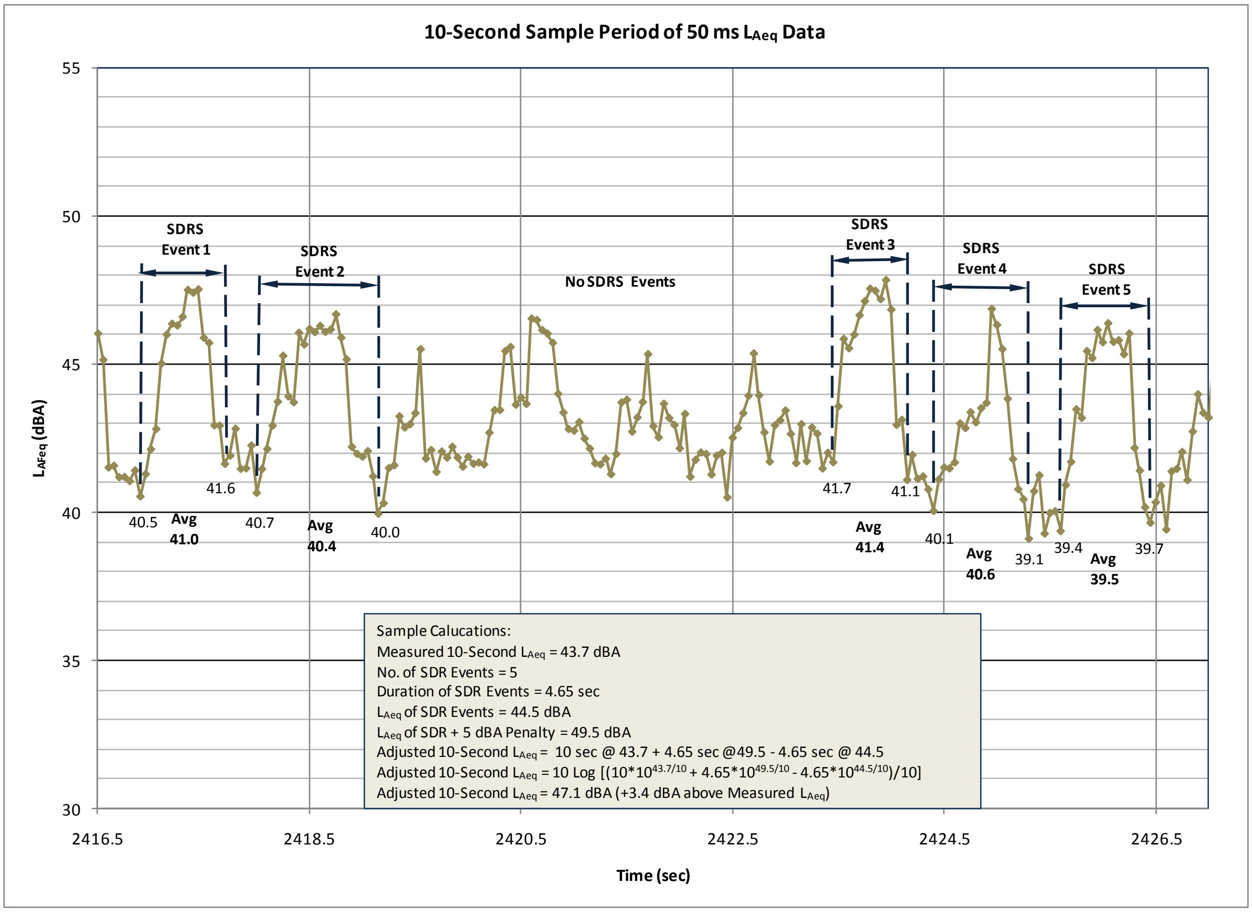


Figure 2. SDR Event Duration and Sound Level Calculation

Concerning assessment of the 5 dBA penalty for SDR sounds, the Maine DEP noise regulation states:

> "For short duration repetitive sounds, 5 dBA shall be added to the observed sound levels of the short duration repetitive sounds that result from routine operation of the development for the purposes of determining compliance with the above sound level limits." (ref. MDEP Chapter 375.10.C.1.e.i.)

The regulation makes a clear distinction that the 5 dBA penalty is to be added to the sound levels of the SDR sounds, and therefore, not to the overall equivalent sound level (L_{Aeq}) for the time period. With this method, more SDR sound events will yield a larger increase in overall sound levels after the penalty is applied.

A sample calculation is provided on Figure 2 that demonstrates how to apply the 5 dBA penalty to the total number of SDR events that occurred during the 10-second measurement sample. The sample calculation indicates there were five SDR events with a total event duration of 4.65 seconds. The L_{Aeq} of the SDR events was 44.5 dBA and adding the 5 dBA penalty increases the L_{Aeq} of these SDR events to 49.5 dBA. The final step is to add the L_{Aeq} of the SDR events with the 5 dBA penalty included to the measured L_{Aeq} of 43.7 dBA for the 10-second period. This step also requires that the measured L_{Aeq} of the SDR events be subtracted out so that the sound levels of the SDR events are not double counted. As shown in the example, application of the 5 dBA penalty will yield an adjusted L_{Aeq} of 47.1 dBA, which is 3.4 dBA above the measured 10-second L_{Aeq}.

In relation to the Sound Testing Protocol, this same calculation method is applied on a 10-minute basis to each of the compliance measurement periods. The first step is to determine the duration and L_{Aeq} of all SDR events that occurred during each 10-minute measurement period. Once this is completed, the 5 dBA penalty is applied to the SDR events in order to calculate the adjusted 10-minute L_{Aeq}. The following provides an example calculation for applying the SDR penalty to a 10-minute measurement.

SDR Assessment – Sample Calculation for 10-minute Measurement Period:

- 10-minute L_{Aeq} (600 seconds) = 45.0 dBA
- Total Time of all SDR Events = 30 Seconds
- SDR Event L_{Aeq} = 50.0 dBA
- SDR Event L_{Aeq} with 5 dBA penalty = 55.0 dBA

Adjustment Calculation:

Adjusted 10-min L_{Aeq} = $10 \text{ Log } [(600 \cdot 10^{45.0/10} + 30 \cdot 10^{55/10} - 30 \cdot 10^{50.0/10})/600]$ = 46.2 dBA*

*Net dBA adjustment = +1.2 dBA

The net dBA adjustment will vary depending on the duration and amplitude of SDR events. The following Table 1 provides examples of SDR adjustments for different measurement results.

ASSESSMENTS FOR SHORT DURATION REPETITIVE SOUND EVENTS

10-Min LAeq	SDR LAeq	SDR Time (sec)	SDR with 5 dBA	Adjusted 10-Min LAeq	Net Change
45	50	5	55	45.2	0.2
45	50	10	55	45.5	0.5
45	50	20	55	45.9	0.9
45	50	40	55	46.6	1.6
45	50	60	55	47.3	2.3
45	48	15	53	45.4	0.4
45	50	15	55	45.7	0.7
45	52	15	57	46.0	1.0
45	54	15	59	46.6	1.6
45	56	15	61	47.3	2.3

Table 1. SDR Assessments for Varying Event Durations and Sound Levels

Tonal Sounds

Maine DEP Chapter 375.10 also applies a 5 dBA penalty to tonal sounds: "For purposes of determining compliance with the above sound level limits, 5 dBA will be added to the observed levels of any tonal sounds that result from routine operation of the development." (ref. MDEP 375.10.C.1.e). Tonal sounds are defined in the Maine DEP regulation as follows:

> "For the purpose of this regulation, a tonal sound exists if, at a protected location, the one-third octave band sound pressure level in the band containing the tonal sound exceeds the arithmetic average of the sound pressure levels of the two contiguous one-third octave bands by 5 dB for center frequencies at or between 500 Hz and 10,000 Hz, by 8 dB for center frequencies at or between 160 and 400 Hz, and by 15 dB for center frequencies at or between 25 Hz and 125 Hz." (ref. Maine DEP Chapter 375.10.G(24)).

The Maine DEP definition of a tonal sound is consistent with "sounds with tonal content" defined in ANSI standard S12.9-2005/Part 4.[1] This ANSI standard is not specific to wind turbines and gives procedures for the "description and measurement of environmental sound."

The first objective of the tonal sound assessment is to determine whether operation of the wind turbines results in tonal sounds at any nearby protected location. For each 10-minute measurement interval meeting the protocol criteria, the Sound Testing Protocol requires that one-third octave band sound levels be reported as "Ten one-minute 1/3-octave band linear equivalent sound levels (dB) with analysis for the presence of tonal sounds."

The "analysis for tonal sounds" is performed by calculating the difference between the third octave sound level at each frequency (Hz) and arithmetic average of the sound levels in the two adjacent third octave bands. For each frequency, this difference is then compared to the threshold criteria in the definition to determine whether a tonal sound occurred during the measurement period.

An example of this calculation is presented in Table 2. In this example, Table 2 shows that a tonal sound occurred in the 160 Hz third-octave band where the tonal difference was 9.2 dBA compared to a threshold of 8 dBA.

[1] ANSI S12.9-2005/Part 4 was first published in 1996, reaffirmed in 2002 and revised in 2005 and well after Maine DEP 375.10 was promulgated in 1989. The definition of "sounds with tonal content" traces its origin to ANSI standard S12.9-1987 Part 3 Annex C. Although Part 3 of ANSI S12.9 also contains guidance on the measurement of one-third octave-band sound pressure levels it does not contain any guidelines with respect to adjustment of sounds with tonal content. Further, ANSI 12.9/Part 4 states that "If sounds are not audible at the location of interest … the adjusted sound exposure for these sounds shall not be included in the total (ref. Table 2 Note 4)."

Third Octave Frequency Hz	Measured Sound Level dB	Tonal Differential dB	DEP Threshold dB	Tonal Sound Yes or No
20	70.5		-	
25	66.7	2.3	15	no
31.5	58.4	-1.3	15	no
40	52.6	0.2	15	no
50	46.4	-3.0	15	no
63	46.1	0.4	15	no
80	45.1	0.1	15	no
100	43.9	-0.1	15	no
125	42.8	-4.8	15	no
160	51.4	9.2	8	yes
200	41.6	-4.4	8	no
250	40.6	-0.5	8	no
315	40.6	0.8	8	no
400	39.1	0.3	8	no
500	37.0	-0.1	5	no
630	35.1	-0.8	5	no
800	34.8	0.8	5	no
1000	32.8	-0.5	5	no
1250	31.7	0.0	5	no
1600	30.5	0.5	5	no
2000	28.4	0.2	5	no
2500	25.8	-0.2	5	no
3150	23.6	0.1	5	no
4000	21.2	0.4	5	no
5000	18.1	-0.5	5	no
6300	16.0	0.8	5	no
8000	12.4	-2.3	5	no
10000	13.3	0.4	5	no
12500	13.3		-	

Table 2. Sample Calculation for Determining the Presence of Tonal Sounds

When tonal sounds occur, the next step is to apply the 5 dBA penalty to each tonal sound as set forth in Maine DEP Chapter 375.10. Section H of the regulation provides measurement procedures and methods for determination of compliance with the DEP Standards. Regarding tonal sounds, Subsection (4.2)(c) states:

> "Identification of tonal sounds produced by routine operation of a development for the purpose of adding the 5 dBA penalty in accordance with subsection C(1)(d) requires aural perception by the measurer, followed by use of one-third octave band spectrum analysis instrumentation. If one or more of the sounds of routine operation of the development are found to be tonal sounds, the hourly sound level component for tonal sounds shall be computed by adding 5 dBA to the one-hour equivalent sound level for those sounds."

This description indicates that the analysis for tonal sounds is based on the one-hour equivalent sound level ("the hourly sound level component for tonal sounds"). The intent of the Protocol is to focus measurements and analysis on 10-minute measurement intervals under stringent test conditions in lieu of hourly sound levels. Therefore, for the Sound Testing Protocol to be consistent with criteria set forth in Maine DEP 375.10, the tonal sound would need to be present in third octave data for the 10-minute measurement interval. Further, the regulation is clear that the 5 dBA penalty is to be applied to each tonal sound that occurs ("if one or more of the sounds … are found to be tonal sounds, the hourly sound level component for tonal sounds shall be computed by adding 5 dBA to the one-hour equivalent sound level for those sounds.") There is no language in the regulation that would indicate that the 5 dBA penalty is to be applied to the overall equivalent sound level or that the penalty should be applied based on the percentage of time that it occurs.

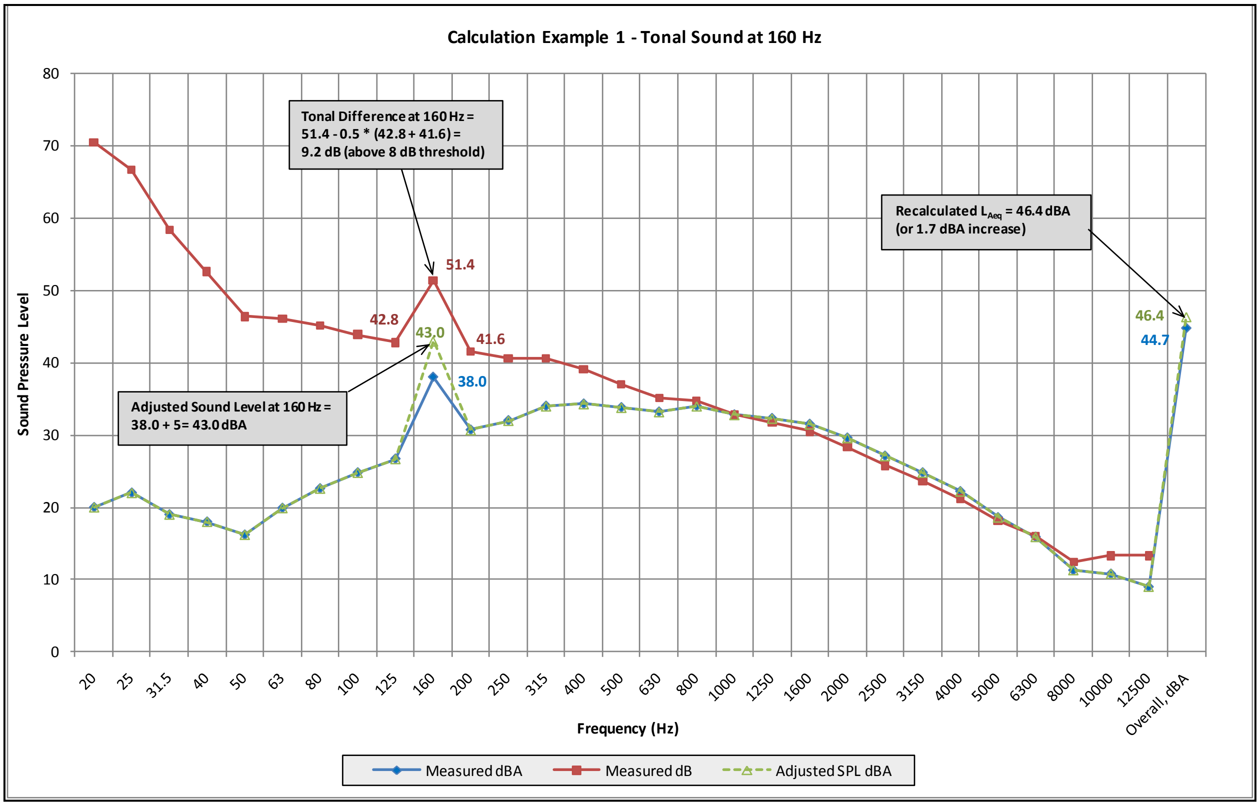
This method for application of the tonal penalty has been used and accepted by the Maine DEP since the noise regulation was adopted in 1989. With this calculation method, application of the 5 dBA penalty to the sound level of the tonal frequency effectively factors in the audibility of the tonal sound at the protected location. Consequently, applying the penalty to a less prominent or less audible frequency would yield a lower net increase or adjustment to the overall A-weighted sound level. Conversely, more prominent tones would result in a higher net increase. Importantly, this ensures that the resultant net increase is a function of the contribution of a particular component frequency to the overall broadband sound level at the measurement location.

As it relates to the Sound Testing Protocol for Stetson II, analysis of third-octave data for the purposes of adding 5 dBA to tonal sounds is to be done using ten-minute measurements in lieu of hourly sound levels. When tonal sounds occur, 5 dBA is to be added to the measured sound level in each third-octave band where tonal sounds are present. The following graphs and tables provide three detailed examples for calculating the change in the ten-minute sound levels that results from application of the tonal penalty.

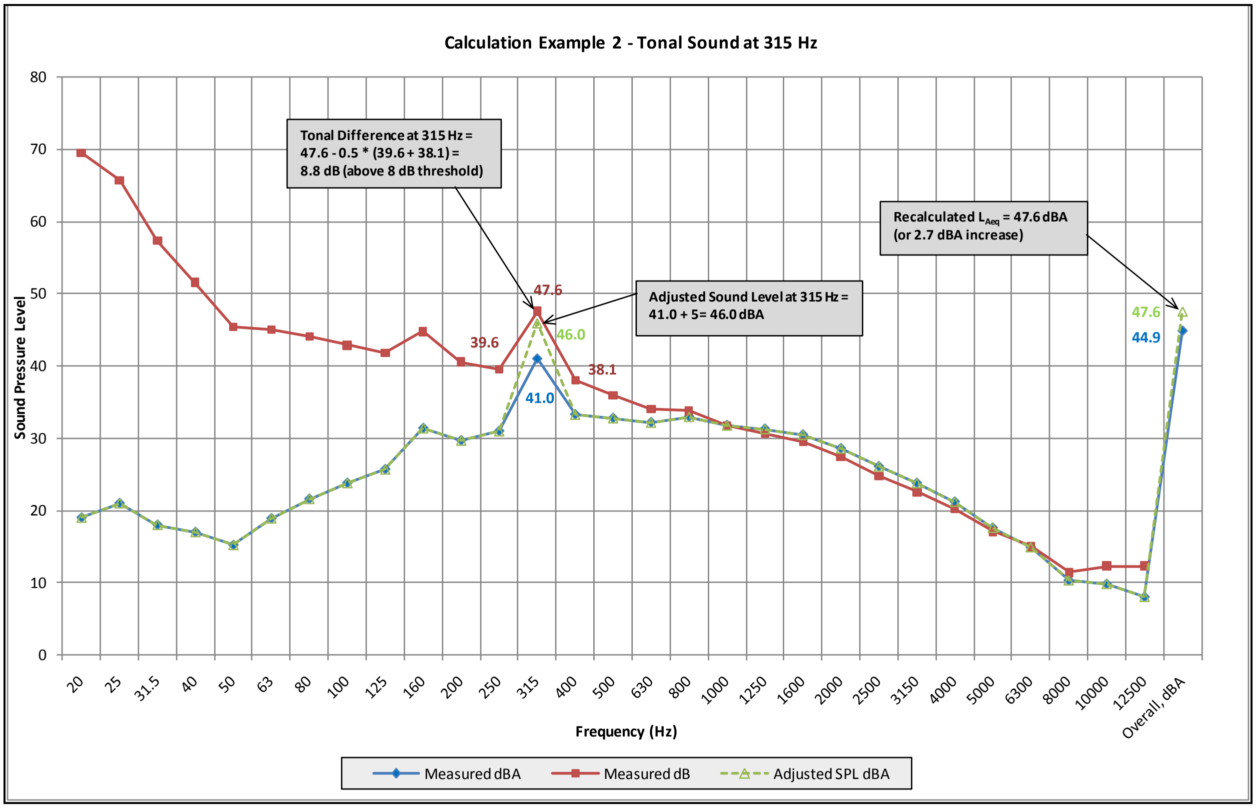
Calculation Example 1 – this example uses the same third-octave measurement results found in Table 2 where a tonal sound is found at 160 Hz. The graph shows the linear third-octave data (red line) used to identify the tonal sound. The other lines on the graph display the measured A-weighted sound levels (blue) and the adjusted A-weighted sound levels (green) with 5 dBA added to the measured sound level at 160 Hz where the tonal sound occurs. The net increase in the overall A-weighted sound level is shown on the right side of the graph. The spreadsheet calculations for Example 1 are shown below the graph. For example 1, the sound level increases from 44.7 to 46.4 dBA, for an increase of 1.7 dBA, with the tonal penalty applied.

Calculation Example 2 – this example shows a tonal sound at the more prominent frequency of 315 Hz. The sound level increases from 44.9 to 47.6 dBA for a net increase of 2.7 dBA.

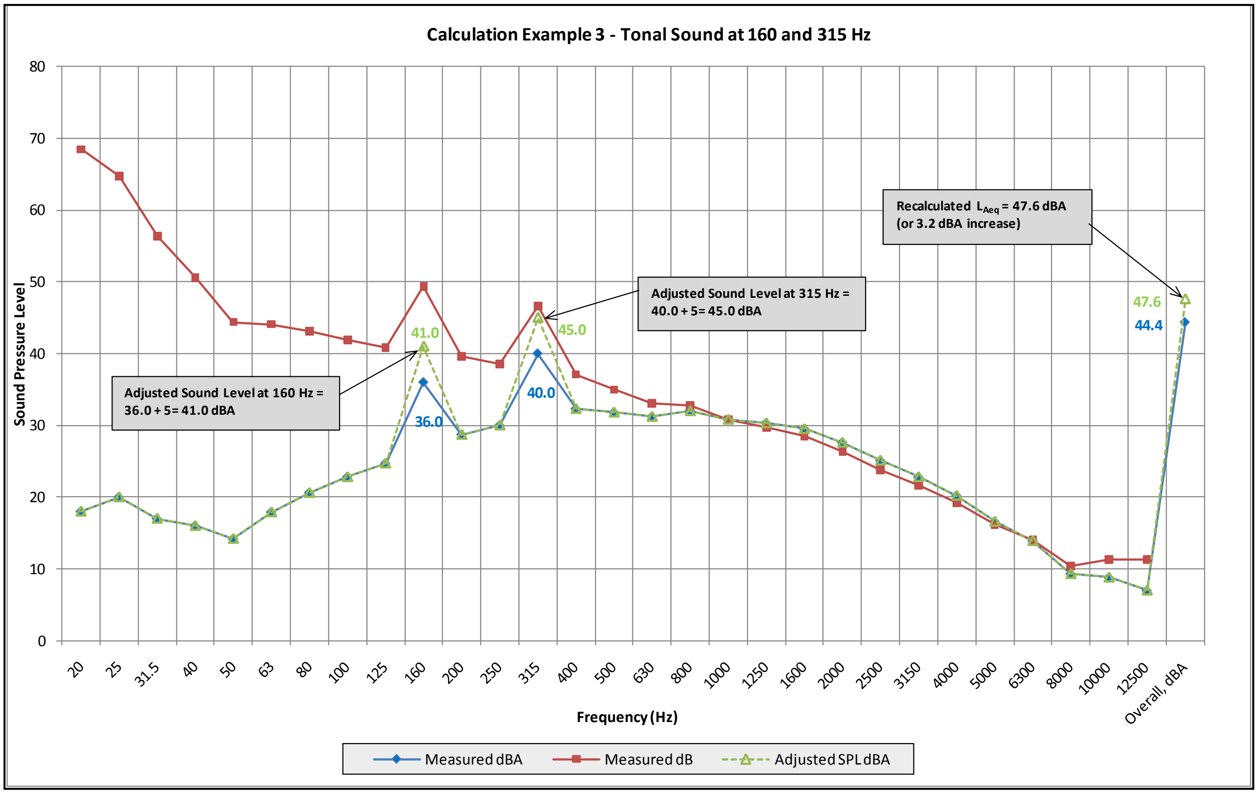
Calculation Example 3 – this example shows tonal sounds at both 160 Hz and 315 Hz. The sound level increases from 44.4 to 47.6 dBA for a net increase of 3.2 dBA.



Example 1								
	Measured		**Measured**	**Tonal**	**DEP**		**Tonal**	**Adjusted**
Frequency	**Sound Level**	**A-Weighting**	**Sound Level**	**Differential**	**Threshold**	**Tonal Sound**	**Adjustment**	**Sound Level**
Hz	**dBA**	**dB**	**dB**	**dB**	**dB**	**Yes or No**	**dB**	**dBA**
20	20.0	-50.5	70.5		-			20.0
25	22.0	-44.7	66.7	2.3	15	no	0	22.0
31.5	19.0	-39.4	58.4	-1.3	15	no	0	19.0
40	18.0	-34.6	52.6	0.2	15	no	0	18.0
50	16.2	-30.2	46.4	-3.0	15	no	0	16.2
63	19.9	-26.2	46.1	0.4	15	no	0	19.9
80	22.6	-22.5	45.1	0.1	15	no	0	22.6
100	24.8	-19.1	43.9	-0.1	15	no	0	24.8
125	26.7	-16.1	42.8	-4.8	15	no	0	26.7
160	38.0	-13.4	51.4	9.2	8	yes	5	43.0
200	30.7	-10.9	41.6	-4.4	8	no	0	30.7
250	32.0	-8.6	40.6	-0.5	8	no	0	32.0
315	34.0	-6.6	40.6	0.8	8	no	0	34.0
400	34.3	-4.8	39.1	0.3	8	no	0	34.3
500	33.8	-3.2	37.0	-0.1	5	no	0	33.8
630	33.2	-1.9	35.1	-0.8	5	no	0	33.2
800	34.0	-0.8	34.8	0.8	5	no	0	34.0
1000	32.8	0.0	32.8	-0.5	5	no	0	32.8
1250	32.3	0.6	31.7	0.0	5	no	0	32.3
1600	31.5	1.0	30.5	0.5	5	no	0	31.5
2000	29.6	1.2	28.4	0.2	5	no	0	29.6
2500	27.1	1.3	25.8	-0.2	5	no	0	27.1
3150	24.8	1.2	23.6	0.1	5	no	0	24.8
4000	22.2	1.0	21.2	0.4	5	no	0	22.2
5000	18.6	0.5	18.1	-0.5	5	no	0	18.6
6300	15.9	-0.1	16.0	0.8	5	no	0	15.9
8000	11.3	-1.1	12.4	-2.3	5	no	0	11.3
10000	10.8	-2.5	13.3	0.4	5	no	0	10.8
12500	9.0	-4.3	13.3		-			9.0
Overall, dBA	44.7							46.4



Example 2								
	Measured		Measured	Tonal	DEP		Tonal	Adjusted
Frequency	Sound Level	A-Weighting	Sound Level	Differential	Threshold	Tonal Sound	Adjustment	Sound Level
Hz	dBA	dB	dB	dB	dB	Yes or No	dB	dBA
20	19.0	-50.5	69.5		-			19.0
25	21.0	-44.7	65.7	2.3	15	no	0	21.0
31.5	18.0	-39.4	57.4	-1.3	15	no	0	18.0
40	17.0	-34.6	51.6	0.2	15	no	0	17.0
50	15.2	-30.2	45.4	-3.0	15	no	0	15.2
63	18.9	-26.2	45.1	0.4	15	no	0	18.9
80	21.6	-22.5	44.1	0.1	15	no	0	21.6
100	23.8	-19.1	42.9	-0.1	15	no	0	23.8
125	25.7	-16.1	41.8	-2.0	15	no	0	25.7
160	31.4	-13.4	44.8	3.6	8	no	0	31.4
200	29.7	-10.9	40.6	-1.6	8	no	0	29.7
250	31.0	-8.6	39.6	-4.5	8	no	0	31.0
315	41.0	-6.6	47.6	8.8	8	yes	5	46.0
400	33.3	-4.8	38.1	-3.7	8	no	0	33.3
500	32.8	-3.2	36.0	-0.1	5	no	0	32.8
630	32.2	-1.9	34.1	-0.8	5	no	0	32.2
800	33.0	-0.8	33.8	0.8	5	no	0	33.0
1000	31.8	0.0	31.8	-0.5	5	no	0	31.8
1250	31.3	0.6	30.7	0.0	5	no	0	31.3
1600	30.5	1.0	29.5	0.5	5	no	0	30.5
2000	28.6	1.2	27.4	0.2	5	no	0	28.6
2500	26.1	1.3	24.8	-0.2	5	no	0	26.1
3150	23.8	1.2	22.6	0.1	5	no	0	23.8
4000	21.2	1.0	20.2	0.4	5	no	0	21.2
5000	17.6	0.5	17.1	-0.5	5	no	0	17.6
6300	14.9	-0.1	15.0	0.8	5	no	0	14.9
8000	10.3	-1.1	11.4	-2.3	5	no	0	10.3
10000	9.8	-2.5	12.3	0.4	5	no	0	9.8
12500	8.0	-4.3	12.3		-			8.0
Overall, dBA	44.9							47.6



Example 3								
	Measured		Measured	Tonal			Tonal	Adjusted
Frequency	Sound Level	A-Weighting	Sound Level	Differential	DEP	Tonal Sound	Adjustment	Sound Level
Hz	dBA	dB	dB	dB	Threshold	Yes or No	dB	dBA
20	18.0	-50.5	68.5		-			18.0
25	20.0	-44.7	64.7	2.3	15	no	0	20.0
31.5	17.0	-39.4	56.4	-1.3	15	no	0	17.0
40	16.0	-34.6	50.6	0.2	15	no	0	16.0
50	14.2	-30.2	44.4	-3.0	15	no	0	14.2
63	17.9	-26.2	44.1	0.4	15	no	0	17.9
80	20.6	-22.5	43.1	0.1	15	no	0	20.6
100	22.8	-19.1	41.9	-0.1	15	no	0	22.8
125	24.7	-16.1	40.8	-4.8	15	no	0	24.7
160	36.0	-13.4	49.4	9.2	8	yes	5	41.0
200	28.7	-10.9	39.6	-4.4	8	no	0	28.7
250	30.0	-8.6	38.6	-4.5	8	no	0	30.0
315	40.0	-6.6	46.6	8.8	8	yes	5	45.0
400	32.3	-4.8	37.1	-3.7	8	no	0	32.3
500	31.8	-3.2	35.0	-0.1	5	no	0	31.8
630	31.2	-1.9	33.1	-0.8	5	no	0	31.2
800	32.0	-0.8	32.8	0.8	5	no	0	32.0
1000	30.8	0.0	30.8	-0.4	5	no	0	30.8
1250	30.3	0.6	29.7	0.0	5	no	0	30.3
1600	29.5	1.0	28.5	0.5	5	no	0	29.5
2000	27.6	1.2	26.4	0.2	5	no	0	27.6
2500	25.1	1.3	23.8	-0.2	5	no	0	25.1
3150	22.8	1.2	21.6	0.1	5	no	0	22.8
4000	20.2	1.0	19.2	0.4	5	no	0	20.2
5000	16.6	0.5	16.1	-0.5	5	no	0	16.6
6300	13.9	-0.1	14.0	0.8	5	no	0	13.9
8000	9.3	-1.1	10.4	-2.3	5	no	0	9.3
10000	8.8	-2.5	11.3	0.4	5	no	0	8.8
12500	7.0	-4.3	11.3		-			7.0
Overall, dBA	44.4							47.6

These examples show how the net increase changes depending on the relative sound level contribution of the tonal sound and how to apply the 5 dBA penalty to tonal sounds at more than one frequency. The data used in these examples is similar to actual wind turbine sound levels but has been revised for the purposes of these examples.

The presence of one or more tonal sounds does not necessarily indicate non-compliance unless the adjusted overall sound level exceeds the Maine DEP quiet limits. The Complaint Response and Resolution Protocol (under separate cover) provides an additional level of protection against tonal sounds that either do not implement the DEP tonal penalty and/or do not result in exceedances of any applicable noise limits, but nonetheless could be annoying.

If tonal sounds develop, the best practice is to mitigate and eliminate these tones. Stetson II will implement measures to minimize the likelihood that tonal sounds will occur and if they do occur, that they will be adequately addressed. The SCADA system and regular inspections by operating personnel would reveal the existence of these types of problems, which may also reduce overall turbine performance. Accordingly, Stetson II's regular inspection and maintenance program for turbines will reduce the likelihood that tonal sounds will occur.

In the event tonal or SDR sounds occur and cause an exceedance of the applicable DEP sound limits, they will be addressed to ensure that Stetson II remains in compliance with the DEP noise standards. If tonal or SDR sounds cause an exceedance of the applicable DEP noise standards, Stetson II will promptly notify LURC and expedite an investigation of the sound level exceedance and the associated tonal or SDR sounds and develop a mitigation plan and schedule to achieve compliance with the applicable sound level limits. Stetson II will provide copies of the mitigation plan to LURC, implement the mitigation plan, and provide a written report describing the action(s) taken and new measurement results that demonstrate compliance. Mitigation options could include reduction of the overall sound level, amplitude modulation, and/or the tonal sound component.