A Model of Ambient Noise Caused by Wind Flow

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Abstract

The generation of noise caused by wind flowing past a human ear is an important yet vastly understudied factor in determining the ambient noise of an environment experienced by a human observer. Sound level measurements were obtained from wind tunnel tests simulating a human experiencing wind flows at various speeds and from various directions. This data set was used in this thesis. This thesis presents a collection of models for predicting wind noise levels across a broad spectrum of frequencies based on wind speed and angle inputs. Graphical approaches are included to characterize the observed data and illustrate the models' performance.

For my family and friends.

Acknowledgements

I would like to thank my family and girlfriend for all of their support during my time at AFIT. The phone calls, texts, and times we were able to spend together helped me keep my chin up through the good and the bad times here at school. I would like to thank my classmates for all of their help, both in and out of class. We have gotten so close during our time here and I look forward to the lifelong friendships that we have made. Finally, I would like to thank Dr. Hill, who always pushed me forward and kept me working hard while always keeping his door open for an encouraging word or entertaining conversation.

Jovan Popovich

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A MODEL OF AMBIENT NOISE CAUSED BY WIND FLOW

I. Introduction

The research for this thesis builds a model to accurately predict the intensity of sound across a wide spectrum of frequencies caused by wind flow past the human ear. The speed of the wind and its angle of incidence relative to the human head encountering the wind are input parameters.

While determining optimal military strategies, it is important to understand whether an enemy may detect any movement of troops, aircraft, and other weapon systems. There are many different means of detection, including visual, radar, and auditory detection; each possessing a unique set of environmental factors that may affect the probability of successful detection. Wind is an obvious environmental factor affecting auditory perception and detection but there has been very little research done on actually quantifying its effect on a human observer.

Anyone who has stood outside on a blustery day will attest that wind can hinder auditory perceptions. While there is an inherent understanding that an increase in wind speed generates more wind noise, it has also been hypothesized that the angle at which the wind flows past the human head and, in turn, the observer's ears, has a significant effect on the intensity of wind noise heard. Limited research has been conducted on this issue. The first and seemingly only significant study on wind angle was Kristiansen & Pettersen [3]. Their study provided a descriptive look at noise generated by wind flow and head angle but provided no model or additional insight on this noise. Other studies, mostly geared towards assessing the performances of various hearing aids, have inadvertently provided descriptive graphs and basic insight

on the effect of head angle and wind noise generation. Overall, this subject matter has gone relatively unstudied.

With an increasing amount of surveillance provided by remotely piloted aircrafts and other technologies, there is hope that the United States military will eventually integrate the visual feeds produced by this data with other forms of data. For instance, wind speed and direction, coupled with aircraft sound profiles in the operational environment could be used to adapt vehicle flight paths to decrease audible detection.

There are also useful applications for this type of model outside of the military. While sound level prediction is useful for the military in determining how to best avoid audible detection, other organizations may find it useful to educate their employees on optimal ways to detect important sounds in windy environments.

This thesis quantifies the impact of wind speed and head angle on wind noise and provides an initial and fundamental predictive model of noise generated by wind flow past the human ear. After providing a brief overview of the basics of sound and acoustics, as well as a look at the literature related to the characterization of wind noise in Chapter II, this thesis discusses the methodology used to fit the data to an accurate model in Chapter III. The model and additional analysis are presented in Chapter IV and conclusions and recommendations for further research are included in Chapter V.

II. Background

Very little research has examined the effect of wind on human auditory perception. There are some results from research not focused on the human ear that are helpful in understanding wind noise effects. Watanabe *et al.* [4] sought to understand how noise caused by wind flowing past a car could be reduced to present a better experience for a car's driver. In this study, it was established that the seperation of the wind flow is responsible for a majority of the wind noise generated. In one of the few studies conducted on the effect of wind on human auditory perception, Kristiansen & Pettersen [3] present the illustration in Figure 1 that clearly depicts wind flow separation.

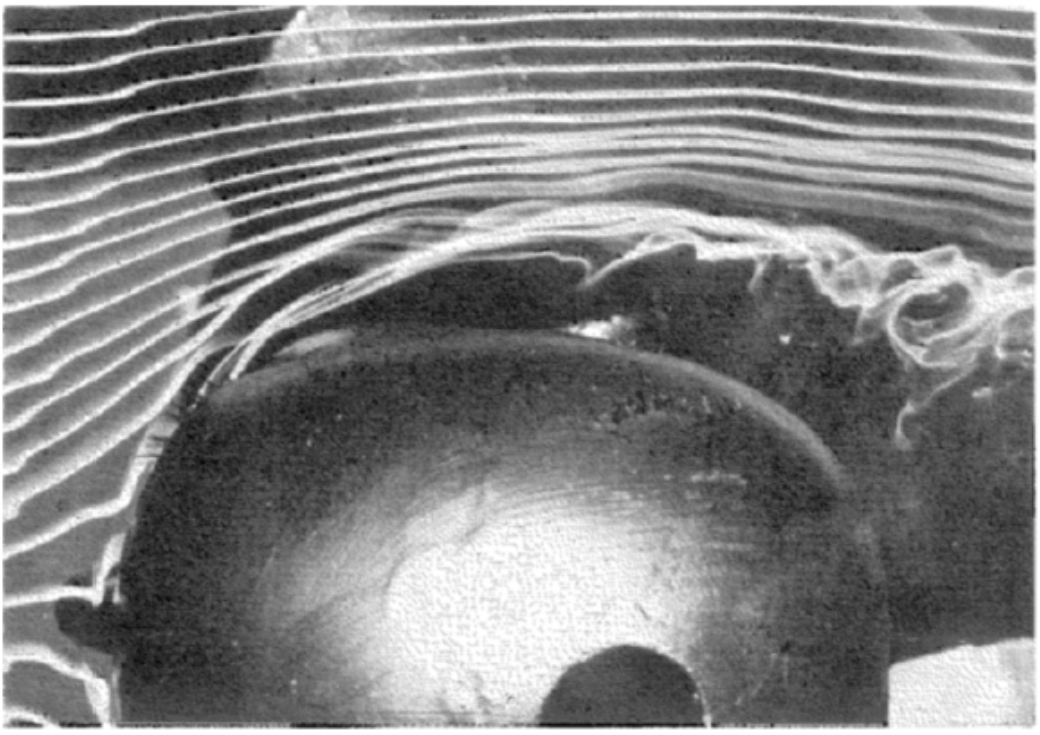


Figure 1. Wind flow seperation around a mannequin head [3]

Figure 1 shows a bird's eye view of smoke streak lines flowing past a shop window mannequin head. The smoke flows from left to right and the mannequin's nose can be

made out in the bottom left corner of the figure, indicating that the head is looking directly into the wind. It is easy to see that the flow separates at the mannequin's cheekbones, causing turbulent air to flow past its right ear, compared to the smooth streak lines shown at the top of the figure. This flow instability is the main reason why humans hear wind.

Kristiansen & Pettersen [3] published one of the few articles that discusses the study of the effects that wind's speed and angle of incidence have on human auditory perception. Angle of incidence is defined as the angle at which the wind stream makes contact with the human head on the horizontal plane, with the 0° angle of incidence being the one at which the head is looking directly at the source of wind. The head's left ear pointing directly at the wind source and the head looking directy away from the wind correspond to the 90° and 180° settings of angle of incidence, respectively.

The authors note that "The noise heard by a person looking directly into a wind is basically of a low frequency nature, with much of its energy concentrated in a certain frequency region. Because of the latter, the noise is often heard as a 'rumbling tone'. With increasing wind velocity the noise level will increase and the frequency region will shift to higher values." Another useful conclusion of this article is that "[The] zero angle of incidence condition is also the one where masking of other sounds plays the most important part, as both ears are subjected to a relatively high noise. For angles much different from zero, the noise levels are lower and usually have a monotonic decrease with frequency." Finally, the article establishes that "At more oblique angles of incidence the flow will be in more direct contact with the ear on the 'upwind' side, but in general less noise will be heard" [3].

Some of these conclusions are illustrated nicely in Figure 2. Figure 2 plots the sound level (in decibels) against the angle at which the wind hits the head on the horizontal plane (with 0° set as the postion that has the head looking straight into

the wind) and the frequency of the sound being measured. This illustration shows that there was more noise recorded at low frequencies as well as angles of incidence close to 0° for a constant wind speed (WS).

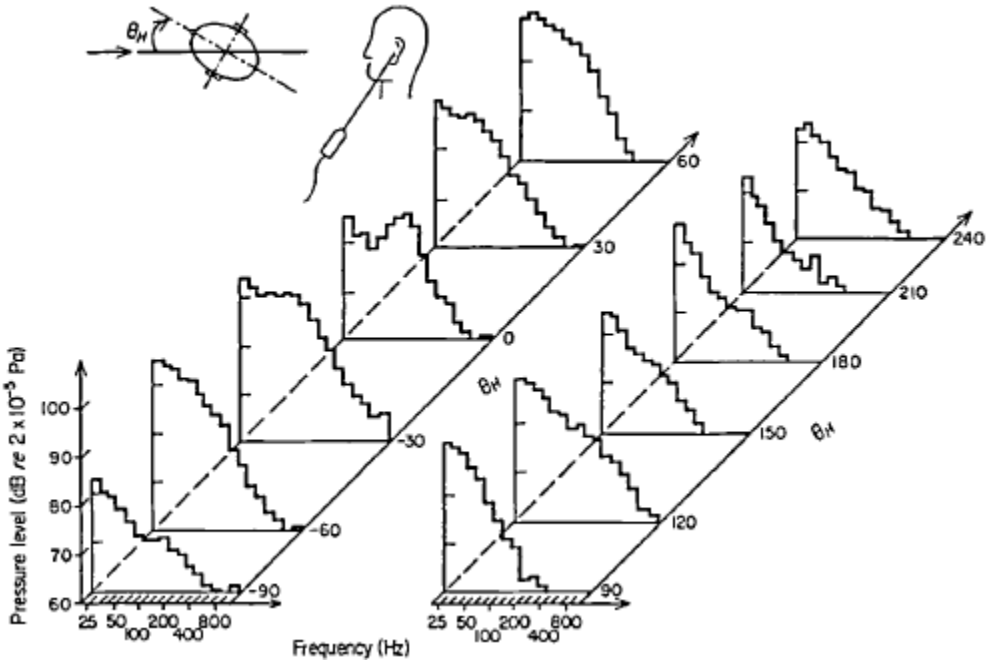


Figure 2. Plot of aerodynamic pressure vs. frequency and head angle, $W = 7.6m/s$ **[3]**

Figure 3 illustrates how wind speed affects the noise heard by humans at the zero angle of incidence ($\theta = 0°$). This figure reaffirms that as wind speed increases, the noise generated by the wind also increases and is characterized by a higher frequency of sound.

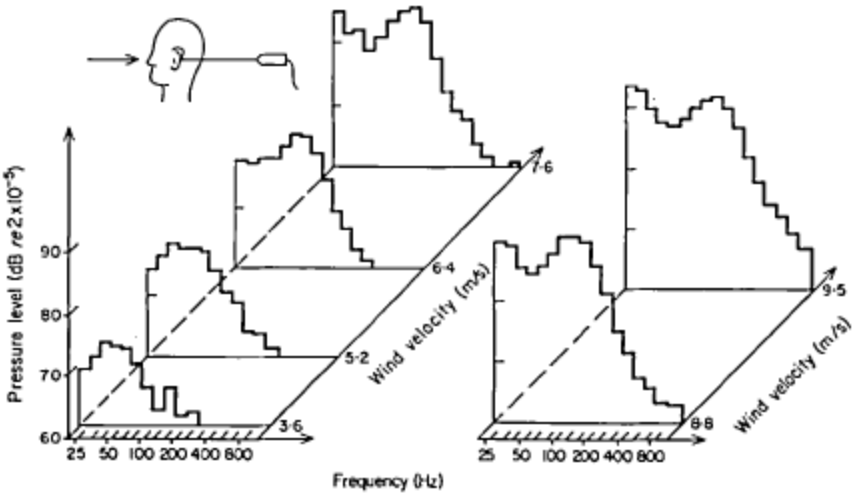


Figure 3. Plot of aerodynamic pressure vs. frequency and wind speed, $\theta = 0°$ [3]

Insight can also potentially be gained from studies conducted on hearing aids. Chung *et al.* [1] conducted a study comparing the performance of two types of hearing aids with wind and its angle of incidence relative to the head as factors. The study found that both microphones "yielded the lowest flow noise levels when the microphones were facing directly upstream. Relatively low levels were also generated when the microphones were facing downstream" and urges hearing aid users with a "good" and a "bad" ear to listen to things with their "good" ear facing into the wind [1]. Figure 4 provides a good illustration of these concepts. Each graph plots the sound level recorded for each type of behind the ear (BTE) hearing aid (directional and omnidirectional) and a particular frequency over a variety of wind speeds and a full rotation of the head.

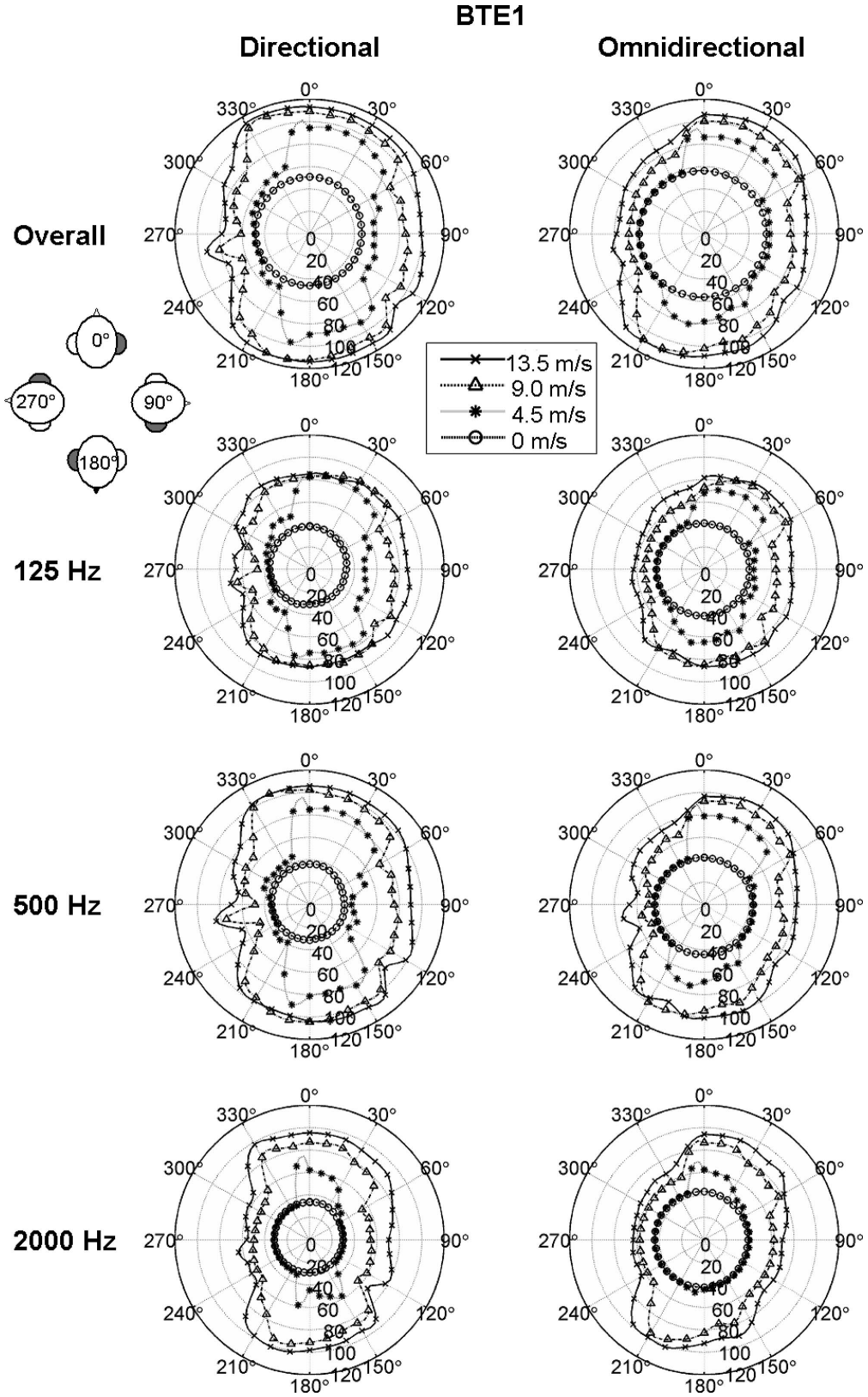


Figure 4. Chung's Results of Experimentation with behind the ear hearing aids [1]

Note the results shown in Figure 4 may not directly correspond to people who do not use hearing aids. Kristiansen & Pettersen [3] note that "Wearers of hearing aids might, however, experience the influence of angle of incidence differently." From previous research, the belief is that hearing aid users will hear the most amount of noise at angles of incidence around 60° and 210° since the wind will be flowing at an angle that will make more direct contact with the hearing aid microphone based on its position behind the ear, in turn generating more noise in the device [3].

Although the literature is sparce, the ambient noise caused by wind over the human ear is important. The next chapter describes how sound level readings as a function of wind speed and head direction are used to build a predictive model of ambient noise.

III. Methodology

Human auditory detection requires the source sound level to exceed the resident ambient sound levels. Gaski [2] examined benign ambient sound levels. To add the ambient noise level due to wind requires sound level data free from other noise sources. The data were obtained via controlled testing. That test is described here but was not part of this research effort.

Sound level measurements were obtained by placing a mannequin head fitted with microphones in each ear into a wind tunnel and systematically rotating the head with wind flowing past. For each wind speed, measurements started with the head facing directly at the wind source and, as the head spun clockwise, were recorded every five to ten degree until the head reached 180 degrees.

The data obtained from this experiment consists of 7502 observations. Measure–ments were taken at 31 distinct sound frequencies (ranging from approximately 10 to 10,000 Hz) resulting in 242 points for each frequency. Each of these frequencies has two sound level measurements that were taken with no wind flow present (one measurement for each ear) and 48 observations for each of the five other wind speeds (ranging from 2.47 to 13.27 m/s). Each sound measurement in the data set has a corresponding frequency, wind speed, and angle setting.

To model the wind noise against a full rotation of the head, rather than only the 180° of rotation represented in the data, an assumption was made that translated the right ear recordings to the second half of the rotation for the left ear. We assumed:

$$dBL_L(\theta) = dBL_R(360 - \theta) \text{ for } 180 \leq \theta \leq 350 \tag{1}$$

With this translation, we assume that the sound levels recorded in the right ear of the head throughout the half of the rotation accounted for in the experiment would

be equal to the measurements heard in the left ear of the head over the second half of the head's rotation, had it occured in the experiment. For example, we assume that the sound levels that would have been recorded in the left ear had the head been positioned at the 270° angle of incidence are equal to the levels recorded in the right ear when the head faced the 90° angle of incidence.

This assumption does not account for the recordings of the microphone in the right ear when the angle is set at $\theta = 0$. The assumption was not made for these observations since 0° and 360° occur at the same place on the polar axis. By not translating this point, an additional assumption is not needed to account for cases when the sound level in one ear is not equal to the sound level in the other due to the random nature of the wind noise. Unforunately, this means that any angle between 350° and 360° falls outside of the region that can be predicted by the model. The recorded sound levels for each wind speed, frequency, and translated angle, excluding the measurements taken with no wind speed present, are included in Appendix A.

Even though many sound level measurements were recorded over a variety of frequencies in this experiment, frequency was not considered as a regressor variable in the modeling process. Instead, the data for each frequency was modeled seperately, as most sounds humans hear are complex sound waves that can be constructed by multiple simple sound waves characterized by only one frequency [2]. Modeling each frequency seperately allows for greater freedom in determining the ultimate sound heard by a human being due to wind.

The sound level measurements recorded with no wind speed present in the exper–iment were excluded from observations used to fit a model to the data. The outlier analysis of any initial models created with these observations being included in the data set almost always tagged these points as outliers and possible influence points. While the exclusion of these points leaves the models unable to estimate wind noise

for any wind speed below 2.47 m/s, it allows for the models to be more accurate over the vast majority of the settings included in the experiment.

The ordinary least squares regression technique was used to find the best fitting model for each frequency. These models were fit and analyzed using JMP 12. To keep the selection of terms used in the model for each frequency unbiased, a formulaic process was used to fit the models to each of the data sets corresponding to the 31 frequencies. First, a polynomial model was fit only using the wind speed as a regressor variable. Polynomial terms up to the fourth order were included and, sequentially, the highest order term was taken out until the highest order term left was significant. After this, a full polynomial model was created with both angle and wind speed as regressor variables and the highest order of the terms in this model corresponded to the order of the model fit exclusively with the wind speed variable. Polynomial terms were then added to this model that only consisted of the angle variable up to the tenth degree. This new model (consisting of up to 21 terms) was run and, similar to the wind speed model creation process, the highest order angle term was removed until the highest order remaining term was significant. At this point, all other insignificant factors were removed and a final model for the given frequency was produced. All terms left in the final models are significant at the 95% confidence level.

All terms with order larger than one were centered to account for the high order polynomials being used in the model. θ_c and WS_c are the centered terms corresponding to the angle and wind speed regressor variables, respectively. These values are determined using Equations 2 and 3 with $\bar{\theta}$ and $\bar{WS}$ being the average values for the angle and wind speed variables across the data set for any given frequency. The values for $\bar{\theta}$ and $\bar{WS}$ are 3.011 radians and 7.754 m/s, respectively.

$$\theta_c = \theta - \bar{\theta} \tag{2}$$

$$WS_c = WS - \bar{WS} \tag{3}$$

Model adequacy was assessed using standard regression modeling methods. Since the focus is on a descriptive model, not a lot of effort was spent on ensuring least squares error distribution assumptions were strictly met.

Model validity will be assessed using graphical methods and model fit data.

The next chapter presents the model developed and its assessment.

IV. Data Analysis

4.1 Data Visualization

For each frequency, a polar chart of the observed sound level plotted against the head's angle of incidence with the wind was created. The charts for frequencies of 125, 500, and 2,000 Hz are included in Figure 5. These charts are representative of all the charts generated. The full suite of charts are provided in Appendix B.

Each line corresponds to a given wind speed as shown in the legend. The level shown at 0° is the sound level recorded in the left ear of the mannequin with the head facing directly into the wind. The level seen at 90° is the level recorded in the left ear with it facing directly into the wind and the level seen at 270° is the level heard in the right ear at this same setting.

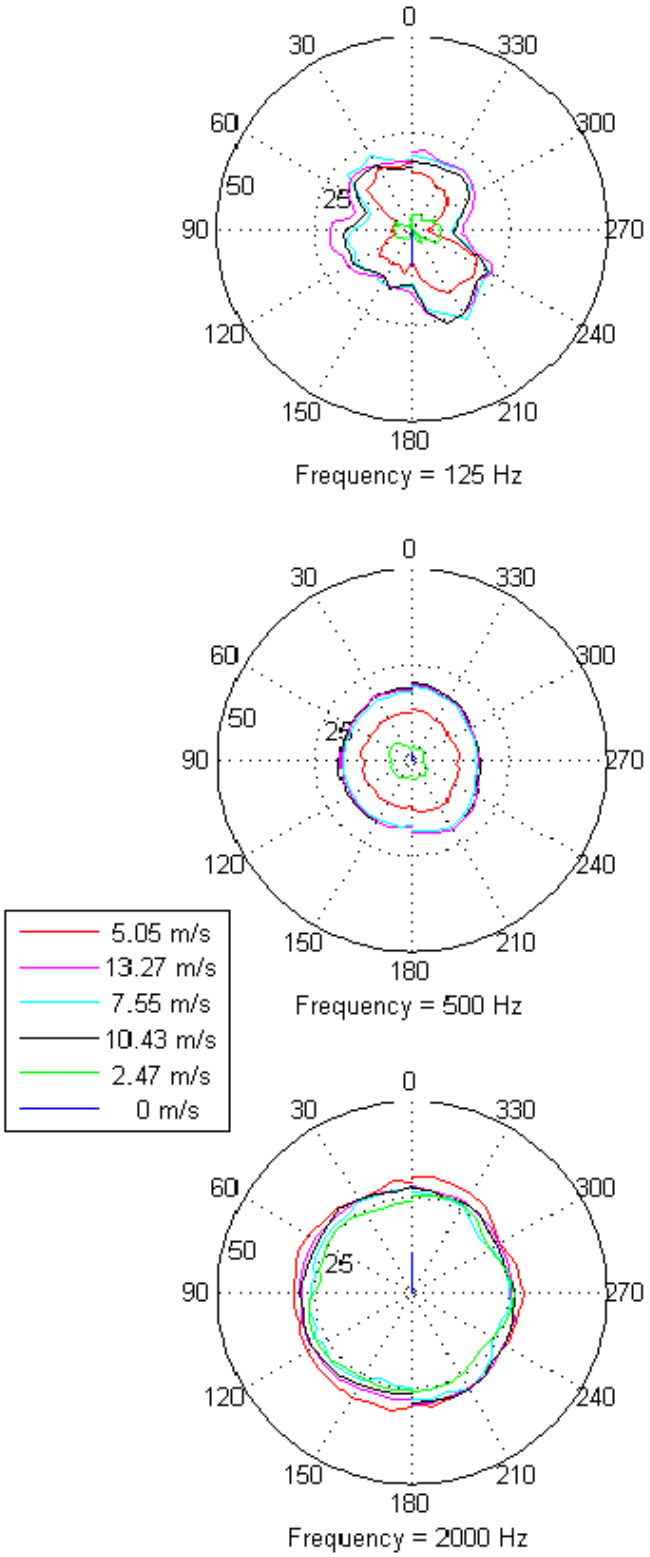


Figure 5. Noise Level (in dB) Plotted Against Head Angle for Frequencies 125, 500, and 2,000 Hz

These graphs seem to echo most of the findings of Kristiansen & Pettersen [3]. As wind speed increases, so does the sound level of the noise generated by the wind. It also seems as though the sound level reaches a limit after a certain wind speed as shown by the fact that the lines seem to cluster together for the higher wind speeds present in the experiment. The graphs for the higher frequencies show the sound levels for every wind speed setting other than 0 m/s clustering together. Most of the low frequencies also show a spike in sound level occuring around 210°. This may be due to the turbulent air flow being created in such a way that it makes more of a direct contact with the ear compared to the turbulent air created at other angle settings. These graphs also show that lower frequencies (up to about 125 Hz) have significantly higher measurements than those in the range from 125 - 2,000 Hz. The sound level then increases for higher frequencies than 2,000 Hz.

The levels recorded at the 5.05 m/s wind speed are particularly interesting. In the lower frequencies, the measurements for this wind speed are just as great, if not greater, than the levels recorded with higher wind speeds present. However, the sound levels for the 5.05 m/s wind speed diminish compared to the levels of the higher wind speeds for higher frequencies. This seems to show how the noise generated by wind may be characterized by a low frequency at lower wind speeds and a high frequency when wind speed increases, as noted by Kristiansen & Pettersen [3].

4.2 Regression Models

One model was fit to the data corresponding to each of the 31 frequencies that sound level measurements were recorded at. Equations 4, 5, and 6 are the prediction equations for the models of frequencies 125, 500, and 2,000 Hz, respectively, with θ and θ_c in terms of radians.

$$\begin{aligned} dBL_{125} = &-13.398 + 0.921 * WS + 7.349 * \theta - 0.321 * WS_c^2 + 11.895 * \theta_c^2 \\ &+0.045 * WS_c^3 - 0.049 * WS_c * \theta_c^2 - 4.879 * \theta_c^3 - 11.835 * \theta_c^4 + 0.905 * \theta_c^5 \\ &+3.658 * \theta_c^6 - 0.051 * \theta_c^7 - 0.446 * \theta_c^8 + 0.0188 * \theta_c^{10} \end{aligned} \quad (4)$$

$$\begin{aligned} dBL_{500} = &6.029 + 0.991 * WS + 1.430 * \theta - 0.358 * WS_c^2 + 0.056 * WS_c * \theta_c \\ &+1.536 * \theta_c^2 + 0.009 * WS_c^3 - 0.004 * WS_c^2 * \theta_c + 0.019 * WS_c * \theta_c^2 - 1.587 * \theta_c^3 \\ &+0.005 * WS_c^4 - 0.004 * WS_c^2 * \theta_c^2 - 0.007 * WS_c * \theta_c^3 - 1.477 * \theta_c^4 + 0.438 * \theta_c^5 \\ &+0.435 * \theta_c^6 - 0.046 * \theta_c^7 - 0.051 * \theta_c^8 + 0.002 * \theta_c^9 + 0.002 * \theta_c^{10} \end{aligned} \quad (5)$$

$$\begin{aligned} dBL_{2,000} = &33.832 - 0.567 * WS - 0.966 * \theta + 0.486 * WS_c^2 - 0.033 * WS_c * \theta_c \\ &-0.542 * \theta_c^2 + 0.031 * WS_c^3 + 0.007 * WS_c^2 * \theta_c + 0.101 * \theta_c^3 - 0.016 * WS_c^4 \\ &-0.003 * WS_c^2 * \theta_c^2 + 0.056 * \theta_c^4 \end{aligned} \quad (6)$$

The coefficients for each model, as well as the model's adjusted R-squared value, are included in Tables 1 – 3. Each column heading represents the frequency at which the model is designated for and each row corresponds to a term in the model. All signifi–cant effects have values present in the table while insignificant effects are denoted by a "–". Certain models were subject to a squared or square root transformation and are denoted with a "*" or "**", respectively.

The average and median adjusted R-squared for the models are 0.91565 and 0.92662, respectively. This means that many of the models are excellent at describing variation present in the data with appropriate terms. No two models fit the data for their respective frequencies exactly the same way. However, there are some trends

Table 1. Regression Model Coefficients

	Frequency										
Parameter	9.843	12.402	15.625	19.686*	24.803*	31.25	39.373	49.606**	62.5	78.745	99.213
Intercept	26.389	22.603	20.444	198.464	117.088	19.474	13.116	3.541	6.910	-7.642	-13.615
WS	0.274	0.667	0.353	55.393	52.712	1.004	0.743	0.090	1.421	1.914	1.050
θ	-0.386	–	–	–	–	-0.262	-0.044	0.171	1.931	4.725	7.013
WS_c^2	-0.218	-0.305	-0.234	-10.491	-7.350	-0.289	–	–	-0.308	-0.247	-0.434
$WS_c * \theta_c$	-0.027	-0.049	-0.039	-1.721	-2.272	-0.054	-0.307	-0.036	–	–	-0.223
θ_c^2	–	3.073	4.674	281.695	387.613	7.705	9.988	0.993	12.151	12.318	10.453
WS_c^3	0.032	0.037	0.029	–	–	0.036	0.024	0.004	0.031	–	0.028
$WS_c^2 * \theta_c$	–	–	–	–	–	–	–	–	–	–	–
$WS_c * \theta_c^2$	-0.034	-0.052	-0.058	-2.450	-2.714	-0.049	-0.047	-0.005	-0.049	–	-0.031
θ_c^3	0.067	–	–	–	–	0.032	-0.006	-0.067	-0.810	-3.545	-5.546
WS_c^4	–	–	–	–	–	–	-0.004	-0.001	–	–	0.008
$WS_c^3 * \theta_c$	–	–	–	–	–	–	–	–	–	–	–
$WS_c^2 * \theta_c^2$	–	–	–	–	–	–	–	–	–	–	–
$WS_c * \theta_c^3$	–	–	–	–	–	–	0.048	0.006	–	–	0.040
θ_c^4	-0.021	-2.429	-3.555	-211.503	-287.279	-5.874	-7.913	-0.824	-10.360	-10.769	-9.702
θ_c^5	–	–	–	–	–	–	–	0.005	0.065	0.694	1.354
θ_c^6	–	0.723	1.020	60.085	80.134	1.651	2.249	0.235	2.986	3.128	2.922
θ_c^7	–	–	–	–	–	–	–	–	–	-0.040	-0.130
θ_c^8	–	-0.090	-0.122	-7.168	-9.353	-0.193	-0.263	-0.027	-0.349	-0.369	-0.351
θ_c^9	–	–	0.000	–	–	–	–	–	–	–	0.004
θ_c^{10}	–	0.004	0.005	0.301	0.385	0.008	0.011	0.001	0.014	0.015	0.015
adj-R^2	0.9140	0.9369	0.8742	0.8470	0.7985	0.9261	0.8307	0.9097	0.8922	0.9141	0.9380

*y^2 transformation

**$\sqrt{y}$ transformation

Table 2. Regression Model Coefficients (2)

	Frequency									
Parameter	125	157.490	198.425	250	314.980	396.850	500	629.961	793.701	1,000*
Intercept	-13.398	-14.482	-2.110	-12.810	-0.429	-3.633	6.029	9.344	12.010	151.704
WS	0.921	1.156	0.615	1.032	0.650	0.793	0.991	0.472	0.539	27.910
θ	7.349	6.628	3.414	5.491	3.358	4.496	1.430	1.083	0.733	–
WS_c^2	-0.321	0.227	-0.162	-0.285	-0.253	-0.209	-0.358	-0.221	-0.213	-4.799
$WS_c * \theta_c$	–	-0.118	-0.058	–	–	–	0.056	–	-0.009	–
θ_c^2	11.895	9.919	9.225	10.717	5.813	3.889	1.536	1.362	1.240	–
WS_c^3	0.045	0.019	0.040	0.024	0.029	0.016	0.009	0.026	0.024	0.226
$WS_c^2 * \theta_c$	–	–	–	–	–	–	-0.004	0.003	0.006	–
$WS_c * \theta_c^2$	-0.049	-0.033	-0.033	–	–	0.014	0.019	0.013	0.013	–
θ_c^3	-4.879	-4.663	-1.360	-3.936	-2.738	-3.542	-1.587	-1.669	-1.618	-43.152
WS_c^4	–	-0.014	–	–	–	–	0.005	–	–	–
$WS_c^3 * \theta_c$	–	–	–	–	–	–	–	–	–	–
$WS_c^2 * \theta_c^2$	–	–	–	–	–	–	-0.004	–	–	–
$WS_c * \theta_c^3$	–	0.020	–	–	–	–	-0.007	–	–	–
θ_c^4	-11.835	-10.494	-9.874	-9.924	-4.463	-3.656	-1.477	-1.214	-1.251	–
θ_c^5	0.905	0.885	0.108	0.740	0.740	0.908	0.438	0.524	0.489	17.150
θ_c^6	3.658	3.292	3.047	2.953	1.228	1.069	0.435	0.334	0.362	–
θ_c^7	-0.051	-0.050	–	-0.042	-0.082	-0.097	-0.046	-0.062	-0.053	-2.262
θ_c^8	-0.446	-0.403	-0.363	-0.350	-0.139	-0.123	-0.051	-0.037	-0.041	–
θ_c^9	–	–	–	–	0.003	0.004	0.002	0.002	0.002	0.099
θ_c^{10}	0.019	0.017	0.015	0.014	0.006	0.005	0.002	0.001	0.002	–
adj-R^2	0.9371	0.9266	0.8720	0.9303	0.9678	0.9750	0.9904	0.9897	0.9946	0.9823

*y^2 transformation

Table 3. Regression Model Coefficients (3)

	Frequency									
Parameter	1,259.921	1,587.401*	2,000	2,519.842	3,174.802	4,000	5,039.684	6,349.604	8,000	10,079.370
Intercept	16.826	179.973	33.832	30.086	34.254	23.817	20.622	22.231	33.918	31.753
WS	0.693	47.480	-0.567	0.639	-0.347	-0.095	0.403	0.160	-0.279	-0.657
θ	-0.323	–	-0.966	-1.003	–	1.745	0.633	–	-2.512	-1.786
WS_c^2	-0.246	-6.205	0.486	-0.428	-0.353	–	-0.049	0.110	0.240	0.455
$WS_c * \theta_c$	-0.007	-1.135	-0.033	0.054	–	–	–	0.012	0.036	0.294
θ_c^2	–	-60.279	-0.542	-0.501	-1.003	-0.292	-0.311	-0.808	-0.420	–
WS_c^3	0.026	–	0.031	0.026	0.022	0.007	0.019	–	0.020	0.026
$WS_c^2 * \theta_c$	0.003	0.212	0.007	0.006	–	–	0.002	–	0.003	0.012
$WS_c * \theta_c^2$	–	–	–	-0.023	0.012	0.011	0.009	0.014	–	0.009
θ_c^3	-0.353	-47.688	0.101	0.102	-0.474	-2.471	-1.443	-0.836	0.674	0.502
WS_c^4	–	–	-0.016	0.006	0.008	–	-0.003	-0.003	-0.009	-0.015
$WS_c^3 * \theta_c$	–	–	–	-0.003	–	–	–	–	-0.001	-0.003
$WS_c^2 * \theta_c^2$	–	–	-0.003	0.004	0.003	–	–	-0.004	-0.002	–
$WS_c * \theta_c^3$	–	–	–	–	0.002	–	0.001	–	–	-0.021
θ_c^4	-0.375	49.253	0.056	0.016	0.442	–	–	0.258	0.069	–
θ_c^5	0.103	17.994	–	–	0.118	0.826	0.491	0.301	-0.091	-0.073
θ_c^6	0.137	-15.024	–	–	-0.084	–	–	-0.039	-0.003	–
θ_c^7	-0.007	-2.357	–	–	-0.007	-0.105	-0.062	-0.038	0.005	0.004
θ_c^8	-0.017	1.842	–	–	0.005	–	–	0.002	–	–
θ_c^9	–	0.105	–	–	–	0.005	0.003	0.002	–	–
θ_c^{10}	0.001	-0.078	–	–	–	–	–	–	–	–
adj-R^2	0.9977	0.9728	0.7882	0.9797	0.9063	0.6985	0.9848	0.8352	0.9666	0.9082

*y^2 transformation

in the significant terms that can distiguish certain groups of frequencies from others. The models for low frequencies (< 500 Hz) are characterized by significantly large coefficitents for the even polynomial angle terms and around 500 Hz, the models be–gin to shift to having significant coefficients for the odd polynomial angle terms. This might indicate that higher frequency sounds generated by wind behave differently than those characterized by low frequencies.

The dominance of even polynomial terms in the lower frequency models seem to make sense considering the Taylor Series approximation of the cosine function. This approximation only includes terms of even degree with alternating signs and decreasing coefficients as the order of the polynomial term increases. While not exact, many of the models for these lower frequencies seem to follow this pattern when considering the terms that do not include the wind speed variable. This behavior intuitively makes sense based on the repetitive nature of the angle measurement and the thought that, if no noise is present in the data, the sound level measured at 0° should be equal to the level measured at 360°.

All model assumptions were checked plotting the residuals on normal plots and against the predicted responses and regressor variable levels. These plots also helped determine that the high order polynomials corresponding to the angle setting were appropriate compared to models that excluded the higher order terms. In most cases, not including the angle terms with order 5 and above resulted in residual vs. angle plots that had a clear trend present in them, all indicating that higher order effects were still needed to validate the constant variance assumption of the model. While some models did not produce graphs that perfectly validate the constant variance assumption, all models will still be useful in providing a point estimate of the noise encountered by a human due to wind.

Figure 6 illustrates the prediction profile for the frequencies of 125, 500, and 2,000

Hz. Similar to the plots present in Figure 5, each line corresponds to wind speed given in the legend with the 0° position set as the head looking straight into the wind. The angle corresponds to a clockwise rotation of the head with respect to the wind source.

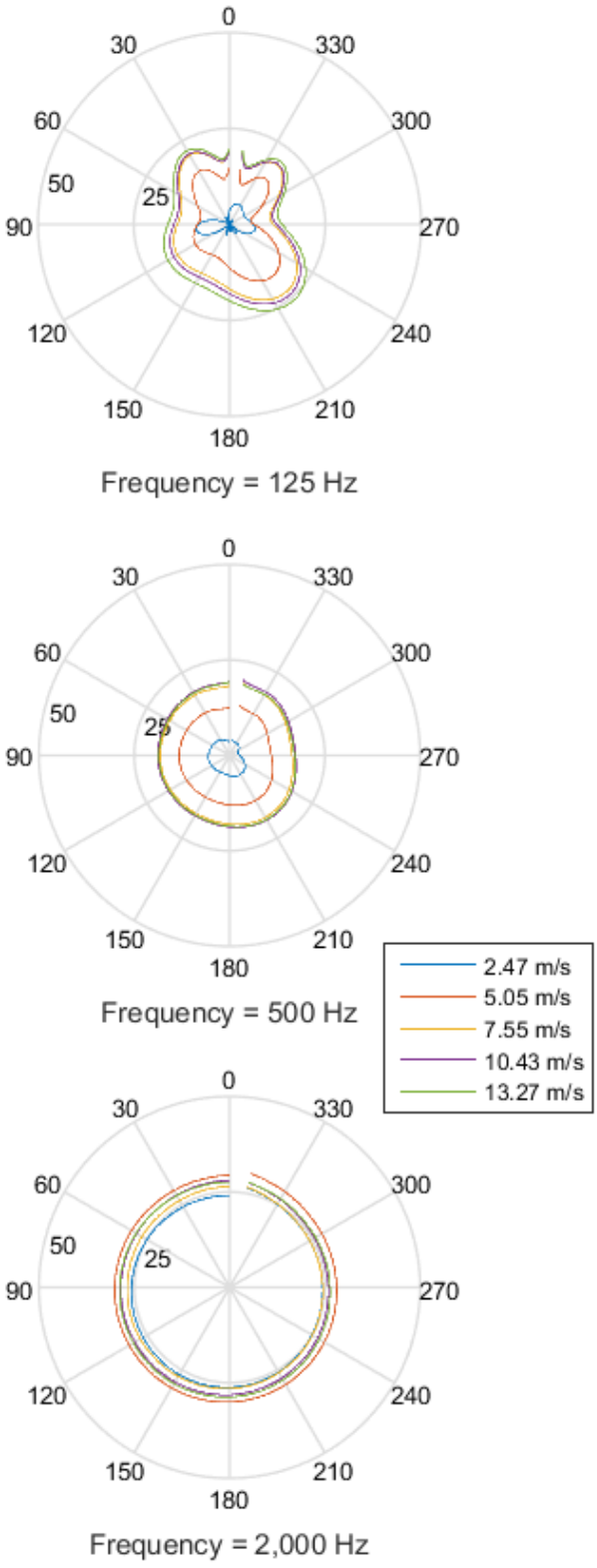


Figure 6. Noise Level Prediction Profile for Frequencies of 125, 500, and 2,000 Hz

The graphs in Figure 6 seem to hold up nicely in comparison to the plots of the acutal sound level measurements present in Figure 5 and Appendix B. The same sort of clustering of wind speeds is present, as is the spike in sound level around 210°. These similarites are reassuring, however a more convenient way to compare the predicted noise level to the actual recorded level for each frequency and wind speed are illustrated in the graphs included in Appendix C. These plots provide another convenient check, confirming that there are no terrible discrepencies between the models' predictions and the recorded sound levels from the experiment.

V. Conclusions and Recommendations

This thesis presents a collection of models that can be used to predict the sound level of noise due to wind heard in a human ear and prior research that was relevant to and helpful with the creation of these models. Through a variety of plots that compared the models to the recorded data and other regression analysis techniques, it was confirmed that the models appropriately fit the data.

There are many opportunites available to further research in this field. The models presented in this thesis could benefit from residual modeling and validation. Residual modeling would be useful in identifying areas where the models perform well as well as giving insight into how the models could be adjusted to perform even better.

More replications of this experiment could reduce noise and lead to a better understanding of how wind speed and angle affect the level of noise produced by wind. For example, it seems like some sort of log transformation on the wind speed variable may be appropriate based on the clustering of wind speeds discussed earlier in this paper. While this transformation was not appropriate for the current data, investigating this issue after conducting more runs may lead to a more intuitive description of wind speed's effect on wind noise and, ultimately, more practical models across all frequencies. Experimenting with faster wind speeds also has the potential of leading to similar findings.

It would also be useful to provide additional runs of the experiment with no wind speed present in the model. This would allow the models to predict sound levels for wind speeds less than 2.47 m/s, speeds that characterize calm days which should not be ignored.

Research could also be conducted to determine if the shape of an individual's head and cheekbones plays a significant role in the level of noise that person hears due to wind. While this information may not be practical for predicting noise levels now, it

could be useful later as technology improves and minute details can be considered.

As discussed previously, these models currently describe a collection of simple sound waves present in the complex sound of wind recorded in the experiment. The predictions of each model could be combined to characterize this complex sound and possibly lead to a better understanding of the wind's overall effect on the ambient noise environment.

The models presented in this thesis are initial models that did not attempt to use any underlying assumptions about the behaivor of wind noise in the modeling process. These models were made to fit the data as best as they could with basic and appropriate terms. This led to models with significant angle terms of very high order and some interesting results concerning the wind speed variable that point to the fact that trigonometric terms and a natural log transformation may be appropriate for the angle and wind speed regressor variables, respectively. These alterations may lead to a model that describes noise generated by wind in a manner more appropriate than the current models do at the expense of not fitting the data as well as the current models.

Ultimately the goal of this research is to understand how a sound signal is affected by the presence of wind. Creating an appropriate model of wind noise is the first step, but more research and experimentation must be conducted on how this wind noise effects a human observer's ability to pick up important signals through the wind. Along these same lines, it is important to consider that wind noise may not be the only factor that impedes a sound signal from being appropriately observed by a human. Researching how wind interacts with the rest of the environment surrounding a listener may prove to be an important endeavor with respect to creating a model that accounts for all of the ambient noise present in a given environment.

Appendix A. Scrubbed Data Set

For Tables 4 –18, each recorded sound level (measured in decibels) corresponds to a frequency (column headings) and angle (row headings). For every wind speed and frequency, there are two measurements each at 0° and 180° (one measurement taken in each ear) so each of these settings has two rows associated with it.

Table 4. Recorded Sound Levels (dB) with Wind Speed = 2.47 m/s

	Frequency										
Angle	9.843	12.402	15.625	19.686	24.803	31.25	39.373	49.606	62.5	78.745	99.213
0	12.939	11.3	11.195	13.31	15.18	12.539	12.449	15.675	13.955	10.895	6.596
	13.528	9.802	10.845	14.491	15.226	12.477	12.908	14.569	12.173	10.022	8.634
10	17.068	15.217	15.299	16.493	18.386	11.824	13.766	13.507	11.162	7.978	6.146
20	17.931	14.741	15.504	17.538	18.977	12.461	14.913	13.536	9.208	5.87	5.209
30	14.304	9.93	15.656	16.209	18.942	12.078	15.19	15.251	9.213	6.104	5.051
40	14.032	10.381	12.623	13.618	16.369	10.738	13.426	12.579	7.594	3.435	3.353
50	16.087	16.851	15.87	16.612	16.226	11.747	12.434	11.31	5.391	1.848	2.106
60	17.258	11.959	13.142	10.194	11.497	8.422	8.164	8.725	0.876	0.011	-0.712
70	13.593	6.143	8.501	6.113	8.531	7.306	6.95	7.979	0.863	4.643	-1.189
75	12.582	8.872	10.079	7.352	9.174	8.662	7.223	7.281	1.873	4.669	-1.336
80	12.737	8.804	10.13	6.358	8.304	8.932	7.639	7.832	1.812	7.528	-0.78
85	14.927	11.11	10.189	5.548	7.95	8.214	7.529	7.682	0.926	6.763	-0.761
90	14.37	10.774	9.909	6.9	8.478	6.985	8.371	7.539	2.275	6.254	-1.25
95	12.445	8.025	10.009	6.459	9.722	8.975	7.155	7.564	2.313	7.216	-0.592
100	15.868	8.35	10.472	7.352	8.261	8.738	8.09	8.159	3.193	8.036	-0.43
105	14.448	9.516	9.299	5.173	6.14	7.745	7.019	7.75	2.893	7.328	-0.652
110	14.442	7.993	8.502	6.713	7.81	7.638	7.842	8.698	3.79	6.852	-0.833
115	18.415	14.894	14.214	12.705	13.345	10.049	10.303	9.592	5.59	6.928	1.424
120	16.104	12.362	14.264	11.029	12.524	9.64	9.594	9.243	5.831	6.373	0.31
130	15.64	14.302	14.377	13.989	13.779	10.87	11.523	10.763	6.282	7.158	1.945
140	14.681	11.832	12.2	13.097	12.102	9.788	11.385	10.806	7.451	6.452	0.858
150	14.741	8.649	10.853	11.129	12.644	9.109	10.648	10.671	4.925	5.984	1.025
160	14.939	8.364	8.856	10.164	11.683	10.093	9.53	9.185	3.784	5.949	0.277
170	12.787	8.519	9.908	12.313	12.608	9.044	9.687	10.403	4.875	5.625	0.137
180	11.457	9.071	10.487	12.573	13.402	8.65	10.586	9.839	4.293	5.967	-0.277
	13.085	10.248	10.345	12.38	12.93	9.517	10.927	9.954	4.73	6.549	0.264
190	14.584	11.484	13.635	15.68	17.008	12.281	13.005	11.677	6.546	6.052	1.68
200	18.057	12.149	14.656	19.389	19.438	15.202	14.321	14.251	9.088	8.766	5.442
210	17.031	13.625	17.091	17.476	19.322	15.487	18.247	16.502	11.305	9.402	8.515
220	16.453	14.853	15.269	17.315	17.2	14.351	16.58	16.163	11.828	8.516	6.3
230	17.162	12.902	14.165	14.52	16.998	13.698	16.322	15.087	11.574	9.289	5.801
240	16.233	14.4	14.024	15.468	17.769	12.823	13.709	13.763	11.895	9.184	4.381
245	18.21	13.735	16.874	15.436	15.387	11.806	12.161	11.799	8.433	6.01	1.996
250	17.837	13.152	13.591	10.637	10.939	9.771	9.346	10.464	6.132	4.367	-0.465
255	14.087	14.599	12.995	9.41	7.938	8.89	8.833	9.893	5.017	4.839	-0.131
260	18.177	10.176	11.982	8.716	9.465	9.884	9.32	10.143	4.975	4.935	0.166
265	15.283	9.542	11.262	7.13	9.913	9.859	8.251	9.477	3.88	4.27	-0.103
270	15.408	11.457	11.931	7.75	9.299	8.035	8.773	9.091	4.198	3.477	-0.689
275	15.8	13.917	10.755	6.838	8.628	9.014	8.475	9.358	3.182	4.195	-0.161
280	14.858	10.812	12.758	8.53	10.75	9.86	8.881	9.82	4.028	4.745	-0.088
285	15.374	12.802	12.186	11.438	11.964	9.497	9.278	9.587	3.825	2.648	-0.312
290	15.497	12.219	13.157	11.784	12.69	9.493	9.192	10.339	3.263	2.596	-0.318
300	14.864	13.306	12.095	12.756	13.709	10.331	9.664	10.533	3.115	-1.423	-0.249
310	13.638	13.316	14.192	13.447	14.296	10.652	10.783	9.301	3.534	-0.639	0.727
320	15.991	12.962	14.233	13.608	16.589	10.674	11.504	11.018	4.617	0.051	-0.058
330	16.292	12.371	12.85	12.662	14.905	10.09	11.175	11.437	4.22	2.35	0.813
340	15.088	12.875	13.779	13.903	15.668	10.667	12.494	10.75	4.903	2.599	1.423
350	16.138	13.475	12.586	14.945	15.84	10.754	12.27	13.316	11.172	7.842	4.483

Table 5. Recorded Sound Levels (dB) with Wind Speed = 2.47 m/s (2)

	Frequency									
Angle	125	157.490	198.425	250	314.980	396.850	500	629.961	793.701	1,000
0	1.931	3.605	0.537	-4.7	-1.237	4.324	2.295	2.118	4.286	8.76
	3.178	5.016	3.142	-2.136	0.077	3.9	3.525	3.29	5.513	10.745
10	1.505	3.991	0.547	-5.037	-0.622	4.386	3.263	2.213	4.611	8.778
20	0.685	3.563	0.573	-5.266	0.178	5.11	3.635	3.272	5.225	8.772
30	0.927	2.521	-0.87	-5.443	0.619	4.855	4.407	3.322	5.74	7.044
40	-0.957	2.161	-1.067	-5.367	0.936	4.761	6.019	3.801	5.648	5.483
50	-3.376	0.891	-2.165	-5.254	1.263	4	6.342	3.708	5.534	7.565
60	-7.464	-0.036	-2.896	-5.246	1.71	4.068	6.516	4.484	6.058	7.346
70	-7.654	-0.791	-3.778	-5.088	2.23	3.427	6.162	4.338	6.342	8.326
75	-7.144	-0.26	-3.795	-4.903	2.435	3.601	6.415	4.569	6.3	10.088
80	-7.593	-0.798	-3.875	-4.528	2.524	3.248	6.218	4.304	6.189	9.957
85	-7.27	-0.591	-3.857	-4.515	2.264	3.183	5.662	4.529	6.223	9.762
90	-7.044	-1.166	-3.471	-3.845	2.499	3.297	5.649	4.664	6.644	9.845
95	-7.439	0.264	-2.97	-4.246	2.73	2.647	5.779	4.362	6.729	10.144
100	-6.397	-0.481	-2.71	-3.941	2.284	2.515	5.111	4.314	6.323	9.53
105	-5.852	-0.095	-2.101	-4.1	1.957	2.505	5.467	4.336	6.674	9.506
110	-6.236	-0.088	-1.59	-3.531	2.115	2.58	5.562	3.907	6.57	8.274
115	-4.817	0.522	-1.135	-3.64	2.202	2.624	5.752	4.194	6.732	7.535
120	-4.251	0.55	-0.411	-3.438	1.977	2.479	5.637	3.95	7.055	6.369
130	-3.222	1.466	0.489	-3.438	1.75	3.179	5.644	3.817	6.897	7.189
140	-3.901	1.533	1.261	-3.288	0.977	3.245	5.588	3.562	6.774	7.17
150	-4.065	2.049	1.383	-3.122	0.715	3.333	5.114	3.756	6.572	6.945
160	-3.703	1.567	1.92	-3.055	0.187	3.828	4.746	3.37	6.107	7.798
170	-3.523	2.155	2.192	-3.078	-0.182	4.009	4.506	3.384	5.767	7.206
180	-3.471	2.186	1.981	-3.34	-0.245	4.012	4.024	3.189	5.169	7.633
	-3.918	2.574	0.415	-4.083	1.13	6.488	5.194	4.291	5.742	7.814
190	-2.736	2.326	0.551	-4.127	0.812	6.276	4.888	4.072	6.126	6.207
200	2.975	5.001	2.556	-3.153	0.888	6.394	4.662	3.604	5.884	5.668
210	4.538	6.365	3.867	-2.078	1.395	5.615	4.583	3.587	5.989	4.328
220	3.169	5.224	2.969	-3.242	1.086	5.487	5.176	3.269	6.053	3.874
230	1.8	2.664	0.529	-4.27	1.588	5.091	4.561	3.028	6.046	4.046
240	-0.236	0.82	-0.461	-4.437	1.307	4.124	4.38	3.039	5.947	2.598
245	-3.072	-0.43	-1.216	-4.691	1.762	4.158	4.133	2.909	5.613	3.624
250	-4.643	-1.146	-1.322	-4.599	1.607	3.872	3.702	2.883	5.294	4.379
255	-3.616	-1.206	-1.266	-4.931	1.503	3.422	3.592	3.094	4.825	5.495
260	-4.122	-1.724	-1.361	-4.781	1.507	3.436	2.704	2.787	4.116	4.776
265	-5.197	-0.875	-1.066	-4.861	2.11	2.966	3.166	2.899	4.553	5.534
270	-4.536	-1.952	-0.705	-4.507	1.864	3.261	2.827	3.148	4.274	4.571
275	-4.46	-1.237	-0.854	-4.963	1.738	2.879	2.93	2.972	3.867	5.183
280	-4.697	-1.316	-0.716	-4.546	1.935	2.663	3.271	2.685	4.019	5.222
285	-3.88	-0.83	-0.798	-4.801	1.992	2.449	3.257	3.098	4.07	5.309
290	-4.583	-0.793	-0.37	-4.531	1.9	2.584	2.982	2.911	4.506	4.756
300	-4.847	-0.396	0.349	-4.422	1.437	2.908	3.317	3.476	4.927	5.423
310	-3.399	0.725	0.947	-4.198	1.35	2.731	3.707	2.899	5.196	5.957
320	-3.353	1.359	1.46	-4.106	1.235	3.621	3.967	3.468	5.764	6.182
330	-2.695	1.686	1.951	-3.523	1.094	3.658	3.252	3.401	5.94	7.933
340	-3.106	2.613	2.344	-3.399	1.267	4.129	3.244	3.664	5.721	9.276
350	-0.7	3.353	2.303	-3.419	0.359	3.682	3.834	3.265	5.549	10.717

Table 6. Recorded Sound Levels (dB) with Wind Speed = 2.47 m/s (3)

	Frequency									
Angle	1,259.921	1,587.401	2,000	2,519.842	3,174.802	4,000	5,039.684	6,349.604	8,000	10,079.368
0	6.823	11.465	23.654	15.128	24.571	26.074	14.712	20.409	22.365	22.212
	8.097	10.103	25.41	16.645	25.605	25.426	14.898	21.329	22.987	21.675
10	6.52	9.073	23.695	14.829	23.572	26.555	14.637	19.689	22.47	22.594
20	6.67	9.863	23.341	14.634	24.212	25.57	14.97	21.632	23.169	23.586
30	6.306	9.419	24.164	15.772	24.819	25.417	15.011	21.89	22.924	22.396
40	6.325	10.187	25.233	16.843	24.791	24.596	15.161	22.171	23.1	22.509
50	6.353	8.657	25.358	16.296	25.056	25.243	16.228	22.898	23.713	23.285
60	6.08	10.605	25.246	16.293	25.153	27.013	16.015	23.539	22.387	21.483
70	6.389	11.538	24.349	16.553	25.469	27.591	16.116	22.735	24.055	23.601
75	6.841	11.91	24.576	17.325	25.728	27.567	16.653	22.852	24.073	23.791
80	6.396	11.495	23.856	17.176	25.521	26.926	16.704	23.052	23.441	23.126
85	6.6	11.954	24.123	17.873	26.347	27.111	17.298	24.226	23.592	23.557
90	6.747	11.823	25.23	18.036	26.426	27.072	17.165	23.825	23.859	23.328
95	6.6	11.914	26.242	18.948	26.779	27.24	16.941	23.77	23.845	23.422
100	6.781	12.939	26.688	19.583	27.171	27.565	17.111	23.005	24.738	23.924
105	7	11.653	27.098	19.339	26.97	27.34	16.599	22.122	24.776	24.071
110	7	11.483	27.426	19.04	26.444	27.369	16.841	23.042	24.14	23.763
115	7.363	11.592	27.495	18.266	26.3	26.933	17.008	23.266	24.564	24.335
120	7.248	10.116	27.425	18.384	25.365	27.506	17.248	23.859	24.943	24.332
130	7.136	10.893	27.117	18.05	25.099	26.567	17.067	23.632	24.609	23.861
140	6.808	9.179	26.219	17.281	25.241	25.559	16.443	22.693	22.432	21.428
150	6.529	10.756	25.794	17.045	26.534	27.324	17.01	24.225	23.51	22.798
160	7.031	10.374	26.058	16.887	27.184	30.728	17.775	22.798	23.095	22.462
170	6.922	10.871	25.839	16.629	26.925	30.079	17.512	23.284	22.7	21.211
180	6.463	10.279	25.527	16.609	27.419	28.296	16.867	21.994	21.887	21.471
	7.128	12.044	25.843	16.827	26.459	29.291	17.987	24.876	23.232	21.722
190	7.125	11.553	25.823	16.668	26.36	30.281	18.531	24.811	22.737	21.417
200	6.946	9.514	25.495	16.216	25.651	31.677	18.391	24.222	21.486	20.109
210	6.308	8.799	24.587	15.589	24.261	31.507	17.668	23.508	22.478	20.675
220	6.313	6.075	23.657	15.257	24.512	28.861	16.959	22.699	20.062	19.074
230	6.415	6.545	22.976	15.131	25.132	26.768	16.438	22.4	20.562	19.511
240	6.091	5.789	23.621	15.517	24.8	26.847	15.924	20.856	20.286	19.418
245	6.132	8.337	24.073	15.733	25.031	26.852	16.345	20.505	20.443	19.931
250	5.946	8.887	24.782	16.745	24.351	26.439	16.055	21.442	19.851	19.541
255	5.576	9.641	25.253	17.747	24.036	25.955	15.815	21.16	20.369	19.797
260	5.247	11.746	25.659	18.142	24.234	25.393	15.696	21.283	20.17	19.418
265	5.44	10.938	26.184	17.647	23.713	24.023	15.156	21.248	20.3	19.831
270	5.074	11.213	26.241	16.788	23.693	22.767	14.863	20.645	20.102	19.751
275	5.087	11.321	25.526	17.253	25.017	23.913	14.679	20.978	19.995	19.726
280	4.865	10.855	25.44	16.678	25.43	24.625	14.277	20.871	19.179	18.986
285	5.242	10.753	24.924	16.489	26.172	25.971	14.686	21.819	19.038	18.502
290	5.102	10.151	24.077	15.653	25.666	26.665	14.926	21.665	19.697	19.096
300	5.208	9.237	22.82	14.328	24.026	25.387	14.135	20.286	19.071	18.565
310	6.124	7.514	23.196	14.084	22.448	25.13	14.248	20.228	20.182	19.959
320	6.569	10	25.403	15.579	23.241	25.498	13.356	18.554	20.433	19.654
330	6.917	7.663	26.146	15.81	23.655	24.956	14.302	20.004	20.829	19.989
340	7.415	7.752	26.211	15.63	23.782	24.822	14.49	22.051	20.711	20.415
350	7.754	7.265	25.926	16.158	23.875	24.856	13.961	20.228	21.317	20.649

Table 7. Recorded Sound Levels (dB) with Wind Speed = 5.05 m/s

	Frequency										
Angle	9.843	12.402	15.625	19.686	24.803	31.25	39.373	49.606	62.5	78.745	99.213
0	23.429	21.644	18.864	17.688	18.409	22.353	20.299	23.887	22.111	18.382	14.598
	22.424	21.082	19.055	19.365	19.347	23.439	19.814	23.018	20.272	17.477	12.925
10	23.952	22.383	21.193	20.722	22.342	23.729	19.756	21.711	20.702	17.382	13.446
20	22.996	22.525	20.227	22.339	24.087	25.202	20.68	23.486	21.294	17.678	14.859
30	25.53	25.412	21.163	21.567	22.94	25.344	22.691	26.397	25.41	20.635	16.752
40	23.773	24.732	21.792	23.12	22.29	24.258	20.572	23.612	23.145	18.234	15.151
50	28.727	28.077	25.451	26.657	25.118	26.174	23.363	24.364	23.06	19.212	14.559
60	30.117	28.111	26.3	26.028	23.32	23.937	19.203	20.311	16.989	12.544	7.848
70	24.263	23.217	20.519	19.382	17.368	19.268	14.46	16.068	12.286	10.035	6.313
75	24.287	22.149	19.586	19.069	17.421	19.888	14.586	15.952	12.158	10.32	5.875
80	23.341	22.577	19.416	17.807	18.327	19.861	15.051	17.595	13.842	10.367	6.268
85	22.913	24.067	19.649	19.966	18.849	21.821	16.238	18.478	14.651	10.764	7.486
90	24.059	23.457	21.183	20.43	20.234	21.549	16.423	18.833	15.382	10.776	6.84
95	24.301	22.123	20.395	19.001	18.45	19.961	14.849	17.062	12.638	10.118	6.709
100	23.903	23.373	19.471	19.9	18.538	19.674	15.618	17.347	13.444	10.491	5.678
105	21.999	22.507	19.503	18.673	15.797	18.398	13.765	15.999	12.422	13.086	6.283
110	23.418	22.551	20.534	20.119	19.095	20.078	14.611	17.231	12.714	14.356	6.729
115	24.527	24.371	21.62	21.039	20.884	21.289	15.889	17.86	13.902	15.595	8.04
120	24.655	26.117	23.562	24.365	24.548	24.639	18.441	21.241	18.238	17.127	9.604
130	25.894	28.536	24.214	23.905	22.561	23.657	19.063	20.889	19.17	17.653	10.677
140	24.257	24.76	20.011	20.413	18.641	21.071	16.603	19.176	18	17.832	9.099
150	24.017	23.508	19.477	19.126	18.611	21.26	16.652	20.181	19.116	18.133	10.399
160	22.8	20.313	18.906	17.234	17.147	20.598	16.864	20.706	18.581	17.018	9.796
170	25.321	23.313	20.29	19.74	20.205	23.016	18.661	21.534	19.513	14.991	10.916
180	22.14	21.317	18.244	17.747	18.745	22.035	17.535	20.868	18.306	13.106	9.01
	21.609	20.678	16.771	19.329	17.863	22.614	18.153	20.608	17.511	12.537	8.653
190	24.308	22.85	19.821	21.238	23.098	26.623	22.766	25.87	24.256	18.737	13.155
200	24.599	23.617	21.861	23.216	23.565	26.714	24.755	30.049	27.751	23.548	16.043
210	23.915	25.182	22.663	23.762	24.274	27.527	24.286	28.574	29.346	28.235	19.419
220	24.733	25.868	23.766	24.909	23.565	26.445	21.875	25.81	26.273	25.739	17.184
230	24.558	26.207	22.216	24.848	23.876	24.619	21.055	24.404	25.145	24.991	18.209
240	22.82	24.855	21.88	25.09	27.845	28.56	23.115	27.338	25.45	23.877	17.052
245	24.518	23.936	22.995	24.907	25.081	27.821	23.937	25.461	23.135	22.78	16.236
250	23.903	24.541	22.378	24.109	23.591	25.833	21.352	23.142	19.102	18.712	12.785
255	24.78	24.094	23.047	22.22	21.302	23.252	17.651	19.084	16.719	14.562	8.984
260	24.946	25.273	21.533	22.653	20.418	21.886	16.302	17.982	13.898	9.274	6.216
265	25.575	24.884	21.527	20.641	18.952	20.858	14.232	17.634	13.169	8.837	6.88
270	23.537	25.032	22.249	20.618	18.78	20.091	14.541	17.921	13.655	8.328	6.673
275	23.088	25.683	22.141	20.009	18.72	21.028	14.959	18.201	13.955	8.653	7.206
280	25.343	25.329	21.451	21.044	19.831	21.898	16.537	19.354	15.291	9.862	7.62
285	25.437	24.529	22.482	22.004	20.237	22.676	17.072	19.644	16.396	11.504	7.814
290	25.5	25.238	21.932	21.572	22.131	23.195	18.08	21.032	17.906	12.518	8.622
300	25.828	25.766	23.318	22.422	20.937	23.931	19.932	22.101	20.805	14.871	10.598
310	25.802	24.686	24.127	23.742	22.401	24.531	20.691	22.93	21.194	16.726	11.75
320	25.748	25.667	21.8	25.046	24.108	25.058	20.8	23.735	22.522	17.787	13.175
330	25.216	24.26	23.287	23.806	23.29	24.216	20.691	22.853	21.097	16.587	12.278
340	22.387	23.453	19.859	22.987	23.407	25.778	19.347	22.592	21.087	16.052	12.453
350	22.457	21.666	21.07	20.621	20.378	25.969	21.562	22.531	20.464	17.19	12.679

Table 8. Recorded Sound Levels (dB) with Wind Speed = 5.05 m/s (2)

	Frequency									
Angle	125	157.490	198.425	250	314.980	396.850	500	629.961	793.701	1,000
0	18.288	19.961	18.877	14.549	12.652	13.992	12.553	12.706	14.355	14.883
	14.71	17.068	16.993	13.375	13.129	13.752	13.217	13.564	15.249	16.349
10	16.206	18.392	16.867	13.897	13.367	14.085	12.591	12.813	14.827	15.37
20	17.121	17.307	15.564	12.656	12.165	13.493	12.716	13.11	15.151	15.194
30	17.913	18.051	16.004	11.8	12.131	12.773	12.402	13.16	15.487	16.054
40	15.715	16.182	13.371	9.407	11.662	12.349	12.843	13.322	15.525	16.104
50	15.477	14.427	11.638	9.012	10.788	11.648	12.602	12.006	15.854	16.415
60	7.357	8.491	5.162	5.31	11.092	11.792	12.574	13.082	15.948	16.828
70	4.465	6.825	3.284	5.057	11.259	11.299	12.898	13.863	16.161	17.493
75	4.162	6.523	3.006	5.098	11.428	11.229	13.19	13.703	16.274	16.976
80	4.806	6.932	2.684	5.171	11.051	11.265	13.405	13.597	16.195	16.821
85	5.488	7.054	2.958	5.28	11.543	11.286	13.683	13.714	16.2	16.405
90	5.54	6.799	3.401	5.373	11.205	11.215	12.612	13.893	15.974	17.952
95	4.925	7.344	2.95	5.63	11.594	10.896	12.249	13.949	16.095	18.097
100	5.298	6.987	2.592	5.427	11.534	11.154	12.96	14.099	15.96	18.025
105	4.594	7.437	3.226	5.07	11.48	11.343	12.947	13.712	16.057	17.787
110	4.877	7.699	3.802	5.807	11.669	11.345	12.974	13.895	15.738	17.783
115	6.866	9.269	5.163	5.558	11.441	11.302	12.949	13.766	15.478	17.649
120	9.331	10.36	7.032	6.352	11.276	11.278	12.86	13.609	15.384	17.072
130	10.801	11.513	8.476	6.932	11.138	11.567	12.282	13.479	15.008	16.963
140	10.232	12.143	8.805	6.765	10.884	11.373	12.942	13.304	15.119	16.583
150	10.635	11.961	9.009	6.227	10.095	11.299	12.64	12.96	14.733	16.305
160	9.685	12.179	8.576	5.516	10.043	11.298	12.786	12.598	14.841	15.906
170	11.663	13.932	10.904	7.545	10.399	10.944	12.814	12.419	14.372	15.485
180	8.757	11.983	8.605	4.969	9.373	10.018	11.837	11.396	14.041	15.045
	8.341	10.71	8.257	5.003	10.237	11.782	12.953	12.562	15.57	15.787
190	13.106	14.441	11.724	8.411	11.14	12.578	13.739	13.267	15.621	15.692
200	16.852	17.129	15.857	13.556	14.278	15.56	13.978	13.485	15.63	15.904
210	19.026	19.154	18.061	15.716	15.809	16.909	14.406	13.906	15.3	15.774
220	18.647	19.193	17.575	14.908	15.273	15.924	14.045	13.465	15.037	15.291
230	20.003	19.868	17.637	13.95	14.556	15.257	12.591	12.984	14.401	15.222
240	18.75	17.937	15.194	11.043	12.684	12.55	12.332	12.306	13.981	14.594
245	18.214	17.396	13.651	8.971	12.065	12.1	12.139	11.977	13.79	14.852
250	12.9	12.694	9.526	6.18	11.825	11.41	11.949	12.023	13.519	14.773
255	7.373	7.622	4.797	3.044	11.341	11.184	11.708	11.575	13.372	14.792
260	4.64	5.621	3.475	3.003	11.428	11.004	11.897	11.91	13.073	14.839
265	4.084	5.938	3.761	2.996	11.444	10.677	10.763	11.801	12.843	14.897
270	4.236	5.391	3.937	2.8	11.17	11.037	11.277	11.704	12.588	14.502
275	4.4	6.272	3.644	2.925	11.676	10.725	12.097	11.653	12.73	13.347
280	5.567	7.163	4.659	3.491	11.323	10.824	11.884	11.527	12.595	13.626
285	6.313	8.312	5.906	4.104	11.921	10.744	11.832	11.672	12.756	13.888
290	7.555	9.161	6.6	4.627	11.958	10.924	11.613	11.872	12.885	14.521
300	9.666	10.487	7.179	4.051	11.52	10.966	11.145	11.506	13.046	14.515
310	11.514	12.174	10.152	6.949	11.18	10.738	11.402	10.895	13.514	14.769
320	13.375	14.606	13.519	10.012	12.97	12.691	12.377	12.68	13.982	14.956
330	12.498	14.765	12.738	9.424	12.359	12.382	12.168	12.61	14.516	15.326
340	14.082	15.552	14.41	11.66	12.944	13.194	12.844	13.044	14.625	15.502
350	14.875	17.529	16.167	13.35	14.229	14.354	12.938	13.307	14.738	16.066

Table 9. Recorded Sound Levels (dB) with Wind Speed = 5.05 m/s (3)

	Frequency									
Angle	1,259.921	1,587.401	2,000	2,519.842	3,174.802	4,000	5,039.684	6,349.604	8,000	10,079.368
0	16.071	15.681	28.723	24.944	27.348	25.733	20.427	21.964	26.549	26.269
	17.387	16.289	30.167	25.483	30.16	26.2	22.163	23.285	26.099	26.147
10	16.066	16.273	29.622	25.104	27.428	25.365	20.264	23.113	26.481	26.013
20	16.477	18.027	28.119	26.086	28.724	26.394	21.97	23.134	26.88	26.473
30	16.655	19.02	28.094	26.307	28.712	27.858	22.62	23.363	27.347	27.026
40	16.936	19.801	29.131	26.695	29.36	28.012	21.243	22.199	26.634	26.498
50	16.959	19.523	29.509	26.788	29.139	27.743	22.969	23.341	27.282	26.663
60	17.103	20.693	30.388	27.491	30.05	29.247	23.891	23.895	27.015	26.397
70	17.345	20.595	31.309	27.56	30.26	28.942	23.958	23.602	27.5	27.249
75	17.206	20.031	31.074	27.182	30.467	28.29	22.754	22.217	26.169	25.844
80	17.376	21.06	30.181	27.647	29.948	27.614	24.261	24.095	27.624	27.217
85	17.296	20.926	30.446	27.347	31.136	28.386	24.353	24.277	27.446	26.799
90	17.34	21.347	30.321	27.462	30.584	29.348	24.289	23.79	27.154	26.587
95	17.215	20.553	30.275	27.551	29.839	29.904	24.347	23.741	27.56	27.03
100	17.425	19.053	30.436	27.19	29.623	28.921	24.406	23.568	27.324	26.698
105	17.4	18.696	29.71	27.088	28.568	28.932	24.895	24.174	27.656	27.031
110	17.404	18.748	30.58	27.219	28.573	28.857	24.634	23.858	27.996	27.282
115	17.546	17.843	30.876	27.625	28.904	27.622	24.448	23.981	27.84	27.467
120	17.321	16.843	30.939	27.137	28.216	27.443	23.533	22.903	26.736	26.268
130	17.413	18.284	31.029	27.754	29.175	27.574	23.919	24.05	27.293	27.15
140	17.245	17.018	31.014	27.129	28.83	27.232	23.52	23.474	27.285	26.926
150	17.281	19.017	31.415	26.729	29.377	27.075	23.235	23.504	26.783	26.452
160	17.076	19.896	30.744	26.106	30.272	26.756	23.211	23.447	26.32	25.912
170	16.916	19.918	31.537	26.587	31.186	27.157	23.233	23.104	25.921	25.265
180	16.539	18.941	29.652	25.463	30.498	27.898	23.469	22.89	25.286	24.462
	17.053	20.453	28.754	26.601	29.678	29.344	24.347	24.68	25.967	25.473
190	17.138	21.014	30.325	27.107	29.212	29.233	24.379	23.949	25.421	25.132
200	17.058	20.475	29.206	25.942	28.708	29.371	24.105	23.618	24.464	24.081
210	16.996	19.11	29.069	25.701	28.533	29.583	23.671	23.387	23.807	23.521
220	16.483	16.295	28.124	25.271	28.815	28.614	23.254	22.672	23.667	23.583
230	16.366	16.59	27.045	25.213	28.948	26.593	22.674	22.423	22.754	22.749
240	15.928	14.509	27.755	24.909	28.437	26.322	21.581	20.471	21.96	21.568
245	15.968	15.458	27.863	25.561	29.474	26.232	22.326	21.541	22.948	22.645
250	15.717	16.105	27.551	25.19	29.213	26.407	21.897	21.129	23.597	23.222
255	15.693	16.162	28.035	25.518	29.371	25.599	21.846	21.149	23.237	22.895
260	15.371	16.549	27.943	25.401	29.748	25.598	21.3	20.706	22.932	22.496
265	15.177	18.063	28.572	25.465	28.984	26.499	21.361	20.969	23.339	22.977
270	15.192	18.827	28.69	25.183	28.629	26.388	21.205	20.974	23.216	22.922
275	15.21	18.243	28.159	24.559	28.368	26.35	21.264	21.496	23.265	22.862
280	15.113	18.165	27.542	24.471	26.696	25.886	21.271	21.45	23.053	22.65
285	14.989	17.214	28.017	23.516	26.173	25.76	19.844	19.825	22.035	21.733
290	15.28	17.533	27.052	23.83	26.573	25.751	21.151	21.076	23.114	22.957
300	15.296	17.852	26.057	23.8	27.176	25.31	21.172	21.451	22.991	22.733
310	15.71	17.099	27.223	23.714	27.141	26.255	21.218	21.216	23.399	23.076
320	16.24	17.968	29.316	24.245	27.229	26.353	19.989	20.052	22.77	22.755
330	16.623	17.89	30.101	24.462	26.276	25.862	20.763	21.809	24.014	23.934
340	16.868	17.732	30.383	24.971	26.73	26.128	21.306	22.084	24.715	24.618
350	16.745	16.455	31.054	24.675	27.454	26.624	21.548	22.836	25.12	25.168

Table 10. Recorded Sound Levels (dB) with Wind Speed = 7.55 m/s

	Frequency										
Angle	9.843	12.402	15.625	19.686	24.803	31.25	39.373	49.606	62.5	78.745	99.213
0	24.084	26.855	21.515	21.594	18.654	23.513	16.425	22.477	25.185	22.807	17.618
	26.428	26.636	21.472	23.238	20.908	25.538	17.75	23.707	27.036	23.043	17.626
10	22.748	24.675	21.039	22.883	23.474	26.037	19.724	22.745	24.726	21.882	16.192
20	22.851	24.494	21.785	23.343	22.014	26.227	20.073	24.101	25.684	22.718	16.991
30	27.067	27.371	23.606	27.74	24.733	28.564	20.579	25.2	29.22	26.69	21.196
40	27.808	28.777	25.785	25.988	25.854	28.793	19.833	24.73	28.227	24.98	19.347
50	29.049	31.958	26.593	29.039	26.927	30.24	23.114	26.853	28.441	25.596	20.463
60	28.03	29.86	27.393	27.7	28.072	31.331	22.043	24.506	26.904	22.102	15.16
70	26.736	28.075	25.528	26.433	24.27	27.618	18.772	20.806	22.575	18.277	12.565
75	27.818	29.55	26.191	26.967	25.456	27.389	18.722	21.149	21.276	19.614	12.123
80	27.61	32.291	25.022	28.578	26.123	27.353	19.725	20.139	20.336	19.829	12.247
85	28.414	28.018	26.566	27.237	26.6	27.891	20.146	22.416	23.542	19.276	13.685
90	26.487	30.652	25.791	28.796	27.404	29.66	21.645	25.45	26.393	20.787	15.164
95	28.093	30.627	26.316	28.129	28.026	30.935	23.97	25.893	27.632	23.671	16.329
100	28.161	28.897	27.644	28.659	27.256	32.886	23.426	26.625	29.399	23.282	16.542
105	26.75	28.834	27.579	29.854	28.452	32.169	24.506	26.956	28.5	23.121	16.941
110	28.112	28.756	25.991	28.983	27.724	31.564	23.396	25.313	27.28	21.981	15.516
115	29.352	29.773	24.915	30.093	28.818	30.527	23.179	26.147	27.449	22.124	15.495
120	27.633	29.735	27.667	30.507	28.096	31.013	23.16	27.371	28.819	23.391	16.993
130	28.622	30.499	29.195	30.443	27.349	28.34	21.848	23.368	25.587	21.834	15.668
140	28.277	29.454	24.732	27.352	22.361	25.621	17.843	20.774	21.39	19.422	14.884
150	26.815	27.234	25.133	24.804	21.294	24.614	15.971	20.861	22.232	19.951	14.92
160	26.899	28.954	22.341	23.741	21.085	24.896	17.266	22.103	23.235	20.262	15.349
170	30.212	29.183	21.491	22.453	21.874	23.898	17.039	20.881	24.28	20.104	14.617
180	27.269	25.762	20.081	21.967	20.681	23.516	16.827	21.723	24.115	20.753	14.401
	27.767	24.622	19.4	22.206	20.516	24.26	17.8	21.823	24.137	20.804	14.458
190	28.115	27.711	21.903	24.349	24.111	27.179	21.478	26.657	31.185	25.496	21.035
200	25.439	26.787	23.219	25.861	23.948	27.627	21.846	28.785	32.719	29.627	24.242
210	26.43	26.921	24.13	25.646	26.128	30.614	23.137	28.74	32.092	28.614	24.743
220	28.248	31.127	25.411	28.038	26.518	31.494	23.726	27.126	29.812	27.124	23.039
230	26.036	28.5	25.47	27.467	24.637	28.637	21.556	24.407	27.512	25.356	20.96
240	27.515	27.499	24.752	25.698	24.862	30.771	25.218	28.558	31.324	27.067	20.691
245	25.964	27.499	22.001	26.313	26.006	28.159	23.928	27.537	30.665	24.198	18.35
250	26.012	26.913	22.967	25.26	25.591	28.275	21.679	25.759	27.346	21.627	15.607
255	25.143	26.944	25.137	26.521	23.55	27.251	20.669	23.925	23.506	19.452	13.884
260	26.131	25.789	24.674	25.963	24.664	28.463	19.294	21.656	21.63	17.819	12.144
265	25.183	27.318	23.775	26.058	24.204	26.213	17.763	19.919	19.925	17.779	11.641
270	25.949	28.098	23.017	24.889	23.302	24.639	17.389	21.402	18.943	16.318	11.595
275	28.388	27.299	23.26	25.572	23.948	25.216	17.355	20.665	20.455	16.53	11.903
280	27.303	29.349	23.378	26.361	24.349	25.801	18.938	20.293	20.403	19.214	12.539
285	26.269	28.504	24.548	25.743	24.406	26.15	18.807	21.306	22.678	19.516	13.274
290	26.983	28.112	24.127	26.606	25.044	27.334	19.665	22.943	25.255	19.353	14.512
300	26.365	28.527	24.188	26.647	24.862	27.784	20.639	24.286	25.474	22.219	16.474
310	26.296	29.784	24.827	26.373	25.57	28.772	21.787	25.632	26.715	23.935	18.43
320	26.539	26.813	24.569	27.037	25.354	28.602	21.503	26.181	28.219	24.589	18.965
330	27.248	26.787	22.739	26.076	24.023	29.105	21.459	25.055	26.004	23.257	17.903
340	26.113	26.851	23.003	24.207	23.104	28.082	20.853	26.242	26.199	23.65	17.732
350	25.026	25.636	21.957	24.434	24.489	26.287	19.105	25.859	27.702	23.317	17.321

Table 11. Recorded Sound Levels (dB) with Wind Speed = 7.55 m/s (2)

	Frequency									
Angle	125	157.490	198.425	250	314.980	396.850	500	629.961	793.701	1,000
0	18.272	15.455	17.091	17.409	18.096	18.916	17.984	16.122	17.922	18.428
	18.947	17.073	16.585	16.788	19.022	19.649	19.392	17.487	18.966	20.118
10	17.955	15.933	17.051	16.552	17.626	19.106	18.303	16.367	18.263	18.571
20	19.006	16.664	17.51	16.78	17.373	17.74	17.615	15.796	18.058	18.539
30	22.271	19.173	19.78	17.805	18.09	18.307	18.231	16.489	18.713	18.869
40	20.746	17.78	17.09	14.898	15.753	16.776	17.754	16.253	18.84	19.239
50	21.823	18.149	17.29	15.214	16.389	16.765	17.86	16.358	18.933	19.708
60	14.834	11.799	9.727	10.099	14.326	15.172	17.95	16.398	19.066	19.637
70	11.625	9.936	7.187	9.314	14.585	15.041	17.96	16.701	19.356	20.023
75	11.613	9.654	7.942	9.195	14.744	14.84	17.781	16.487	19.168	20.003
80	12.222	9.801	6.674	9.189	14.76	15.233	17.908	16.766	19.221	20.162
85	13.152	9.962	7.547	9.462	15.021	15.042	18.028	16.76	19.462	20.408
90	15.295	11.211	9.569	9.943	15.231	15.714	17.813	16.94	19.225	20.265
95	16.205	12.936	10.522	10.733	15.01	15.189	18.141	16.932	19.202	20.275
100	17.015	12.814	11.341	10.775	15.166	15.497	18.129	16.625	19.081	20.215
105	16.828	13.265	11.029	11.012	15.063	15.189	17.974	16.415	18.971	20.136
110	16.052	13.039	11.276	11.268	14.755	15.302	17.886	16.74	18.905	20.033
115	16.377	13.184	11.913	11.973	15.589	15.566	18.05	16.741	18.83	20.143
120	17.41	14.585	12.586	12.068	15.414	15.654	17.884	16.463	18.684	20.06
130	16.056	13.763	11.959	11.747	15.165	15.719	18.078	16.549	18.528	20.171
140	15.252	13.967	11.952	10.979	15.048	15.274	17.969	16.224	18.391	19.747
150	16.164	14.064	12.024	10.678	14.447	15.281	17.728	16.069	18.079	19.74
160	16.117	14.108	12.243	11.624	14.606	15.514	17.544	16.027	17.838	19.263
170	15.335	14.335	11.117	9.55	13.973	14.819	17.548	15.861	17.525	19.202
180	14.938	13.3	11.218	9.245	13.42	14.538	16.955	15.307	17.705	19.169
	14.276	12.064	10.477	8.703	14.028	16.277	18.277	16.677	18.947	19.664
190	21.524	16.722	15.38	13.111	15.862	17.318	18.53	17.034	18.536	19.364
200	23.348	19.376	18.536	17.255	18.429	20.048	19.484	17.808	19.05	19.262
210	27.235	21.626	20.502	18.71	19.838	20.981	19.82	17.946	19.055	19.504
220	24.501	21.6	20.916	19.285	19.61	20.353	19.455	17.279	18.695	18.971
230	22.88	20.513	20.755	19.602	19.063	19.657	18.846	16.848	17.803	18.535
240	22.633	19.785	19.887	17.559	18.032	17.821	17.779	15.284	17.188	17.736
245	19.929	17.715	18.211	16.34	17.071	16.924	17.444	15.121	16.692	17.485
250	17.031	14.681	14.326	12.41	15.226	15.681	17.009	14.791	16.406	17.359
255	13.681	10.781	9.116	8.247	14.62	14.775	16.665	14.454	16.08	17.288
260	11.012	8.075	6.771	6.459	14.753	15.005	16.562	14.439	16.092	17.363
265	9.809	7.645	5.597	6.294	14.645	14.434	16.697	14.554	15.858	17.364
270	9.777	7.188	5.371	6.236	15.053	14.88	16.128	14.616	15.693	17.369
275	10.303	8.066	5.871	6.347	14.988	14.606	16.481	14.435	15.908	17.577
280	10.849	9.362	6.876	6.983	14.935	14.726	16.522	14.495	15.768	17.649
285	12.544	9.879	8.695	7.855	15.094	14.408	16.51	14.224	15.832	17.729
290	13.921	11.121	8.997	8.743	15.282	14.788	16.681	14.575	16.303	17.99
300	16.404	13.109	11.255	10.058	15.136	14.544	16.704	14.694	16.605	18.282
310	19.295	15.661	14.238	13.098	16.213	15.869	16.855	15.071	17.052	18.714
320	20.367	16.957	15.776	14.976	17.407	18.102	18.175	16.175	17.964	19.066
330	18.682	16.116	15.057	14.002	17.37	17.754	18.269	16.365	18.142	19.295
340	18.739	16.211	16.212	15.932	18.11	18.554	18.424	16.759	18.408	19.263
350	18.832	17.398	16.819	16.544	18.916	19.928	19.369	17.535	19.031	19.84

Table 12. Recorded Sound Levels (dB) with Wind Speed = 7.55 m/s (3)

	Frequency									
Angle	1,259.921	1,587.401	2,000	2,519.842	3,174.802	4,000	5,039.684	6,349.604	8,000	10,079.368
0	20.227	23.079	27.473	29.831	30.216	25.922	22.688	21.338	24.322	22.112
	21.721	23.698	26.261	30.21	29.456	26.915	24.086	23.038	24.122	21.987
10	20.564	22.97	27.073	29.988	28.748	25.867	23.18	22.136	24.893	22.532
20	20.481	22.532	26.945	30.104	29.146	26.229	23.568	22.455	25.205	22.999
30	20.815	22.359	27.515	30.577	30.289	26.419	23.85	22.432	24.953	22.507
40	20.959	22.579	26.547	31.065	30.537	27.441	24.669	23.253	25.59	23.399
50	21.385	23.045	26.369	31.296	31.492	27.737	24.969	23.275	25.669	23.254
60	21.339	24.107	26.554	31.843	31.581	28.214	25.328	23.475	25.757	23.106
70	21.349	24.438	26.22	31.807	31.76	28.462	25.505	23.615	25.735	23.299
75	21.333	24.655	26.491	31.764	31.452	28.177	25.372	23.355	25.507	22.927
80	21.544	24.861	25.491	31.945	31.092	28.736	25.69	23.855	25.86	23.351
85	21.497	24.903	26.173	31.848	31.344	28.704	25.694	23.741	25.768	23.333
90	21.377	24.975	25.996	31.886	31.805	28.765	25.907	23.789	25.777	23.405
95	21.445	24.957	26.44	31.914	31.637	28.997	25.7	23.673	25.722	23.193
100	21.423	25.139	26.71	31.901	31.453	29.196	25.907	23.81	25.902	23.532
105	21.34	24.853	26.231	32.051	32.084	29.205	25.896	23.807	25.879	23.627
110	21.557	24.615	26.151	32.234	30.827	29.239	25.921	23.912	26.051	23.734
115	21.374	24.149	27.736	32.263	30.618	29.107	26.041	23.957	26.19	23.924
120	21.313	23.654	26.299	31.985	30.952	28.503	24.692	22.571	24.576	22.289
130	21.353	23.215	27.53	32.278	31.386	28.498	25.804	23.818	26.134	23.707
140	21.491	23.275	27.192	31.82	31.245	28.437	25.732	23.749	25.861	23.476
150	21.161	22.536	26.457	31.402	31.564	27.692	25.27	22.718	24.387	21.921
160	21.323	22.315	23.808	31.181	31.917	28.447	25.401	23.22	24.838	22.337
170	21.228	22.337	24.505	30.816	31.227	28.289	25.352	22.933	24.475	21.708
180	20.93	22.794	24.953	30.753	30.712	28.308	25.473	22.462	23.701	21.165
	21.184	23.926	27.701	31.518	31.166	29.03	26.739	24.342	24.331	21.654
190	21.286	23.229	28.274	31.4	32.283	29.13	26.256	23.95	24.008	21.242
200	21.048	22.906	27.473	31.293	31.971	29.325	26.005	23.459	23.202	20.51
210	20.789	22.671	29.346	31.05	31.662	28.597	25.554	22.312	21.7	19.076
220	20.303	22.723	27.651	30.606	30.562	28.82	25.433	22.76	22.449	20
230	20.018	22.283	26.501	30.497	30.822	28.288	24.912	22.386	22.164	19.951
240	19.395	21.873	23.59	29.846	31.528	27.259	23.232	20.605	20.36	18.304
245	19.487	22.236	24.329	30.122	30.918	27.217	24.296	21.83	21.793	19.699
250	19.464	22.283	23.571	30.072	30.622	27.113	23.922	21.702	21.699	19.594
255	19.204	22.484	24.062	29.765	30.952	27.134	23.782	21.529	21.587	19.557
260	19.184	22.423	25.099	29.453	29.218	27.266	23.681	21.55	21.55	19.47
265	19.121	22.376	25.323	29.456	29.185	27.107	23.329	21.46	21.395	19.102
270	18.902	22.218	25.09	29.205	28.77	27.009	23.351	21.492	21.587	19.442
275	19.268	21.994	25.126	28.859	28.717	26.508	23.072	21.556	21.637	19.443
280	19.384	21.962	24.969	28.741	29.464	26.435	23.032	21.746	21.769	19.488
285	19.184	21.698	25.314	28.491	29.802	25.947	22.837	21.204	21.454	18.933
290	19.411	21.583	24.486	28.651	30.369	26.317	23.046	21.62	21.698	19.242
300	19.633	21.476	23.274	28.999	29.931	26.145	23.03	21.445	21.823	19.383
310	20.109	20.748	22.366	28.861	29.486	25.786	23.056	21.48	21.943	19.657
320	20.398	21.043	23.618	28.953	28.947	26.312	23.105	21.703	22.011	19.97
330	20.731	21.42	25.954	29.012	28.961	25.861	22.869	21.441	21.881	19.704
340	20.899	22.06	26.178	29.184	29.05	26.545	23.407	22.093	22.936	20.979
350	21.655	23.099	26.507	29.948	29.642	26.857	23.801	22.687	23.664	21.554

Table 13. Recorded Sound Levels (dB) with Wind Speed = 10.43 m/s

	Frequency										
Angle	9.843	12.402	15.625	19.686	24.803	31.25	39.373	49.606	62.5	78.745	99.213
0	23.849	24.017	19.384	23.227	21.251	23.393	17.807	22.065	23.635	23.873	16.104
	23.822	25.878	21.04	25.134	23.668	26.98	21.051	24.973	27.105	27.655	18.521
10	23.243	24.854	18.642	22.366	21.455	25.47	19.801	24.108	25.137	24.932	15.54
20	22.652	22.454	18.022	23.54	23.134	25.464	20	24.496	25.363	25.772	16.625
30	26.783	29.694	22.95	26.15	25.65	28.396	21.933	25.194	26.532	26.533	18.256
40	25.729	28.774	24.237	27.951	27.34	30.395	23.529	26.751	27.403	26.315	17.901
50	25.953	27.958	24.612	28.273	29.765	32.688	25.339	28.447	30.997	27.881	18.198
60	28.234	29.557	23.789	29.555	28.538	32.073	25.207	28.812	29.245	26.99	17.887
70	28.173	28.774	24.482	28.939	26.64	30.311	23.143	26.02	25.161	22.851	14.369
75	26.104	30.089	25.081	29.016	27.27	31.26	23.436	25.706	25.887	23.976	14.507
80	28.56	29.734	25.036	31.195	28.465	31.26	25.025	27.036	26.863	25.26	15.159
85	27.43	28.889	24.467	30.379	29.077	31.498	25.315	28.139	27.644	25.886	16.42
90	30.174	30.114	26.305	31.02	28.917	32.281	26.849	30.609	30.285	27.32	18.02
95	30.116	29.123	25.45	30.569	29.493	31.981	26.393	30.259	30.374	27.956	18.689
100	28.874	30.833	25.109	30.14	29.288	34.358	27.565	32.207	31.078	29.395	18.846
105	26.631	31.745	28.463	31.654	29.978	33.042	28.016	31.404	31.946	29.723	18.871
110	27.495	30.941	26.882	29.965	28.354	32.435	27.973	31.652	31.493	29.254	19.524
115	27.057	29.336	25.99	28.845	29.155	32.139	27.06	31.378	30.699	27.984	17.726
120	28.131	29.797	24.789	30.093	29.056	32.111	26.277	29.353	30.84	28.809	19.081
130	28.05	30.294	25.934	28.591	30.226	31.097	24.703	26.427	26.275	26.076	16.236
140	27.47	28.006	23.86	28.005	28.636	29.193	20.822	23.552	22.5	21.693	13.627
150	27.304	28.419	22.342	26.826	24.691	27.468	17.923	21.443	21.588	22.056	13.398
160	28.229	32.85	25.966	27.393	25.352	28.251	20.436	24.562	24.388	24.382	16.301
170	27.154	28.374	25.381	25.636	21.781	24.74	17.846	22.189	21.172	22.35	15.682
180	26.141	28.944	22.847	24.43	19.973	25.043	18.273	22.519	23.287	23.81	14.224
	28.022	29.771	21.719	22.527	20.334	25.055	18.822	23.506	24.194	24.393	14.517
190	28.104	28.875	23.53	26.584	23.759	27.873	21.627	26.819	28.601	29.418	21.921
200	25.299	29.217	23.434	25.303	24.753	30.825	23.592	28.361	29.71	31.292	25.381
210	27.123	29.573	22.383	25.76	25.611	31.08	24.406	28.851	31.128	31.166	23.771
220	26.251	26.434	24.216	28.543	29.236	32.689	25.094	29.272	29.909	28.805	21.708
230	26.657	27.814	24.515	26.937	26.631	29.067	22.716	26.873	27.775	27.326	19.182
240	25.877	29.562	23.029	28.358	26.834	29.709	24.148	31.6	33.035	31.223	22.779
245	25.843	26.58	22.731	25.228	25.084	27.869	23.777	29.52	30.286	29.799	20.359
250	25.306	25.539	22.129	26.18	24.68	28.204	22.988	27.226	28.47	26.669	17.36
255	23.413	27.243	24.152	26.587	26.153	29.83	22.759	26.134	25.496	24.052	13.881
260	26.637	25.975	21.965	25.812	25.885	28.853	21.834	25.643	22.751	21.612	12.069
265	27.212	27.412	21.522	26.948	25.833	26.921	20.838	23.601	21.834	19.994	12.397
270	27.357	27.025	23.284	26.95	25.807	28.076	20.17	24.827	22.416	19.763	12.127
275	25.937	26.89	22.434	26.861	25.679	28.018	20.833	23.872	22.655	20.808	13.121
280	26.067	26.399	22.292	27.3	24.986	28.159	20.866	24.505	22.742	22.343	13.441
285	24.862	28.434	23.659	26.961	25.415	28.598	22.198	25.222	24.415	23.04	13.732
290	26.543	27.433	22.605	26.454	24.76	28.949	21.917	25.611	25.755	23.708	15.407
300	25.776	27.126	23.77	28.587	25.984	28.876	22.905	26.869	26.759	25.561	16.998
310	25.767	28.485	22.736	26.938	27.39	29.113	22.643	26.398	28.106	26.123	17.222
320	24.61	27.692	23.86	26.829	26.123	29.274	23.808	27.91	28.727	26.943	17.459
330	26.221	30.434	22.213	25.151	25.444	27.867	21.933	27.064	28.429	25.658	17.21
340	25.134	25.966	21.812	24.353	23.6	26.392	21.341	26.821	27.696	27.286	18.262
350	25	27.791	20.859	24.04	22.15	26.366	20.254	25.006	26.628	28.338	17.928

Table 14. Recorded Sound Levels (dB) with Wind Speed = 10.43 m/s (2)

	Frequency									
Angle	125	157.490	198.425	250	314.980	396.850	500	629.961	793.701	1,000
0	16.204	18.325	13.761	14.682	16.487	18.52	18.929	16.845	18.731	19.669
	17.525	19.744	15.798	16.716	18.084	19.962	20.222	18.006	20.096	21.323
10	15.864	18.494	15.253	16.084	17.334	19.462	19.29	17.211	18.983	19.878
20	16.717	19.607	16.035	17.37	17.95	19.592	19.309	17.372	19.324	20.231
30	18.937	21.655	17.903	19.268	19.18	20.584	19.604	17.713	19.693	20.434
40	19.111	21.771	17.277	17.031	17.1	18.013	18.44	16.702	19.365	20.555
50	19.191	21.45	17.308	17.272	17.12	17.85	18.687	16.875	19.45	20.503
60	16.662	18.417	12.807	13.234	15.433	15.963	18.589	16.711	19.398	20.901
70	12.422	13.96	9.302	11.141	14.804	16.16	18.422	16.854	19.77	21.07
75	13.271	14.082	9.62	11.777	15.669	15.637	18.453	17.077	19.66	21.15
80	13.932	15.315	9.39	11.768	15.767	15.792	18.552	17.053	19.908	21.174
85	14.714	16.068	10.814	12.349	15.446	15.822	18.572	17.258	19.84	21.204
90	17.424	18.897	12.656	13.495	16.101	16.359	18.926	17.229	19.869	21.252
95	17.819	19.385	13.212	13.926	16.067	16.319	19.018	17.248	19.712	21.255
100	17.713	19.133	13.48	13.969	16.15	16.457	18.99	17.249	19.777	21.421
105	17.891	19.446	13.934	14.858	16.374	16.469	19.084	16.974	19.716	21.223
110	17.238	19.303	13.769	14.411	16.265	16.286	18.662	17.114	19.604	21.241
115	17.22	18.96	13.352	14.452	16.168	16.241	18.954	17.234	19.616	21.196
120	17.994	19.393	13.601	14.143	16.162	16.083	19.005	16.785	19.384	21.221
130	16.366	18.26	13.06	13.992	15.512	16.151	18.672	16.945	19.247	20.893
140	14.279	16.348	12.352	12.868	15.279	16.181	18.571	16.492	18.826	20.816
150	14.336	16.374	12.433	12.765	15.078	15.842	18.539	16.468	18.858	20.542
160	16.837	18.052	14.138	13.756	15.718	16.625	18.371	16.104	18.691	20.447
170	14.649	16.344	11.615	11.142	13.997	15.014	17.767	15.685	18.382	20.319
180	14.627	16.338	11.079	10.547	14.124	14.843	17.406	15.645	18.36	19.997
	14.65	16.546	11.581	10.857	14.664	16.682	18.94	16.992	19.512	20.583
190	21.801	23.108	17.332	16.71	16.532	18.33	19.22	17.103	19.391	20.555
200	26	25.661	20.47	19.203	19.374	20.896	20.344	18.003	20.051	20.719
210	25.579	28.554	22.964	21.735	20.106	21.818	20.806	18.778	20.282	20.762
220	23.301	26.051	21.351	20.675	19.674	21.003	20.091	17.904	19.226	20.164
230	21.273	24.816	20.293	21.084	19.953	21.07	19.642	17.264	18.689	19.658
240	22.12	23.713	19.234	19.849	19.326	19.35	19.014	16.052	17.891	19.135
245	19.722	21.672	17.36	18.77	17.972	18.021	18.529	15.792	17.753	19.123
250	15.346	17.726	14.465	14.908	16.347	16.877	17.683	15.494	17.258	18.731
255	13.02	14.664	10.984	10.715	15.582	15.897	17.653	14.884	17.059	18.54
260	11.273	11.87	7.401	8.434	15.18	15.457	17.447	15.142	16.833	18.554
265	10.557	10.411	6.812	7.55	15.292	15.396	17.45	15.043	16.635	18.542
270	10.839	11.438	6.564	7.457	15.225	15.252	17.392	14.759	16.565	18.777
275	11.476	11.615	7.417	7.947	15.141	15.128	16.937	14.985	16.435	18.83
280	11.782	12.772	7.536	8.548	15.548	15.234	17	14.9	16.667	18.693
285	13.06	13.481	8.589	9.704	15.904	15.018	16.788	15.076	16.561	19.076
290	13.639	14.842	10.081	10.079	15.255	15.756	16.985	15.214	17.055	19.195
300	16.596	18.001	12.467	12.516	15.905	15.705	17.195	15.3	17.211	19.468
310	18.081	19.625	15.261	14.399	16.551	17.244	17.896	15.961	17.919	19.746
320	18.556	21.371	16.206	15.803	17.333	18.633	18.664	16.861	18.896	20.578
330	17.394	19.494	14.961	15.107	17.149	18.755	18.936	17.255	19.321	20.742
340	17.434	19.888	15.982	16.455	17.79	19.212	19.759	17.858	20.181	21.306
350	17.247	19.27	16.31	17.086	18.437	20.143	20.221	18.37	20.051	21.21

Table 15. Recorded Sound Levels (dB) with Wind Speed = 10.43 m/s (3)

	Frequency									
Angle	1,259.921	1,587.401	2,000	2,519.842	3,174.802	4,000	5,039.684	6,349.604	8,000	10,079.368
0	20.919	24.582	27.674	26.486	26.83	25.765	23.764	22.458	24.889	22.345
	22.349	25.219	27.259	27.05	27.338	26.649	25.262	24.238	24.728	23.916
10	21.178	24.639	26.965	27.647	27.328	26.047	24.167	23.095	25.183	22.009
20	21.329	24.706	27.354	27.599	26.791	26.418	24.679	23.512	25.63	22.079
30	21.543	24.976	28.247	28.627	27.38	26.826	25.132	23.881	25.979	22.506
40	21.737	25.201	28.902	28.902	28.092	27.159	25.623	24.208	25.965	22.246
50	21.769	25.158	28.031	28.301	28.286	27.094	25.884	24.166	25.926	22.302
60	22.04	25.511	27.76	28.32	28.957	27.638	26.264	24.507	26.185	22.655
70	22.04	25.466	27.782	28.908	29.345	27.85	26.335	24.486	26.168	23.242
75	22.21	25.654	27.934	30.672	29.055	27.993	26.584	24.651	26.233	22.938
80	22.147	25.649	27.669	32.474	29.954	28.068	26.705	24.795	26.355	22.845
85	22.03	25.689	28.495	32.595	28.671	28.214	26.84	24.694	26.266	22.6
90	22.136	25.743	28.646	32.619	29.316	28.092	26.824	24.837	26.368	22.445
95	22.041	25.613	28.383	32.675	29.325	28.155	26.825	24.798	26.403	22.765
100	22.086	25.691	28.516	32.492	29.003	28.234	26.807	24.782	26.412	22.822
105	21.957	25.561	28.812	32.555	29.49	28.213	26.851	24.846	26.625	22.782
110	22.029	25.575	29.024	32.555	29.365	28.116	26.895	24.981	26.564	22.907
115	21.975	25.386	29.056	32.453	28.953	28.184	26.842	24.992	26.691	22.884
120	22.128	25.303	29.341	32.343	29.37	28.224	26.865	24.883	26.725	22.848
130	22.125	24.983	28.486	32.124	29.266	27.968	26.653	24.712	26.502	22.807
140	22.048	25.19	28.634	32.215	28.649	28.083	26.751	24.758	26.368	22.804
150	21.963	24.817	27.84	31.895	27.817	27.931	26.668	24.404	25.679	22.428
160	21.993	24.597	27.126	31.908	28.62	27.855	26.719	24.385	25.525	22.849
170	21.779	24.537	26.746	31.749	28.8	28.135	26.433	24.003	25.029	22.601
180	21.486	24.229	26.43	31.441	28.635	27.923	26.215	23.611	24.406	22.854
	21.987	25.332	28.96	32.235	29.117	28.713	27.464	25.453	24.934	22.63
190	21.677	25.186	29	32.199	28.892	28.596	27.186	25.026	24.604	23.825
200	21.996	25.115	29.114	32.009	28.757	28.31	27.056	24.703	24.17	22.73
210	21.755	24.948	29.037	31.703	27.45	28.213	26.72	23.971	23.329	22.184
220	21.205	24.596	28.429	31.399	27.639	27.889	26.38	23.852	23.275	21.892
230	20.853	23.803	27.321	31.048	27.861	27.342	25.775	23.326	22.878	22.118
240	20.407	23.641	27.382	30.572	27.787	27.139	25.481	23.145	22.711	20.891
245	20.15	23.505	27.052	30.348	27.284	27.038	25.287	23.037	22.647	20.8
250	20.107	23.433	26.936	30.399	27.757	26.908	25.078	22.855	22.515	21.284
255	20.01	23.276	26.736	30.15	27.705	26.887	24.869	22.715	22.584	22.082
260	19.94	23.268	26.076	30.059	27.388	26.588	24.65	22.641	22.406	22.556
265	19.833	23.16	26.249	30.03	27.775	26.458	24.513	22.61	22.516	22.571
270	19.936	23	26.411	29.789	27.232	26.269	24.411	22.686	22.566	22.151
275	19.856	22.726	26.178	29.634	26.628	26.375	24.346	22.672	22.546	22.315
280	19.958	22.696	24.902	29.451	27.509	26.183	24.243	22.749	22.648	22.559
285	20.067	22.478	24.818	27.696	26.755	26.053	24.173	22.724	22.612	22.964
290	20.14	22.54	24.958	26.235	27.002	26.081	24.129	22.588	22.651	23.799
300	20.258	22.786	25.124	25.791	27.291	25.994	24.123	22.634	22.761	23.214
310	20.492	23.121	25.579	26.266	27.522	25.801	24.095	22.513	22.536	21.155
320	21.211	23.688	26.848	27.17	27.39	26.138	24.239	22.707	22.87	21.64
330	21.465	24.162	27.245	27.402	26.375	26.158	24.296	22.965	23.351	23.331
340	21.869	24.521	26.457	26.904	26.022	26.395	24.643	23.198	23.674	23.486
350	22.21	24.913	27.072	27.539	27.14	26.501	24.894	23.754	24.216	23.913

Table 16. Recorded Sound Levels (dB) with Wind Speed = 13.27 m/s

	Frequency										
Angle	9.843	12.402	15.625	19.686	24.803	31.25	39.373	49.606	62.5	78.745	99.213
0	24.61	23.433	18.806	21.117	20.89	25.152	18.704	22.804	23.454	22.635	18.699
	24.804	25.13	20.967	22.431	21.898	27.169	22.362	25.876	26.866	25.339	23.295
10	23.672	24.691	17.885	22.065	20.918	26.501	19.097	24.827	26.774	23.98	19.529
20	25.203	26.611	18.837	20.277	21.08	25.852	19.609	24.105	25.149	24.82	20.189
30	26.91	26.408	22.897	23.359	24.307	28.652	23.422	26.973	26.466	25.053	20.927
40	26.078	27.762	21.561	25.228	25.312	31.07	25.937	27.761	27.335	25.575	21.352
50	24.911	27.537	24.605	25.573	27.706	33.28	28.146	30.629	32.13	29.252	22.848
60	25.737	29.821	23.568	26.43	28.821	32.543	27.232	29.332	30.415	26.581	21.759
70	29.216	30.134	24.882	27.971	28.403	33.63	26.436	29.06	29.182	25.204	18.986
75	27.82	29.987	25.365	25.813	27.505	32.166	25.182	28.349	28.313	24.528	18.444
80	27.412	28.739	23.288	27.009	27.524	33.81	27.198	29.327	29.985	25.985	19.501
85	26.386	31.565	24.357	28.229	30.488	35.244	27.999	31.762	32.981	28.905	23.197
90	27.418	31.019	25.34	28.251	28.667	32.602	28.396	32.851	32.824	30.312	24.183
95	29.211	30.897	25.84	27.67	27.946	33.176	27.948	32.101	34.121	29.474	23.895
100	26.006	29.993	25.342	29.786	28.888	33.296	28.455	32.731	33.347	29.979	24.067
105	28.886	30.231	23.948	27.182	28.388	34.449	28.34	33.199	33.285	29.675	23.469
110	27.237	29.601	23.223	25.801	28.869	32.188	28.425	31.704	33.302	29.312	22.827
115	27.19	29.004	24.261	25.396	27.66	32.095	27.025	31.737	32.785	28.649	21.96
120	27.62	30.212	25.339	26.502	27.583	33.773	27.214	32.082	32.508	28.417	22.267
130	30.338	30.078	22.441	24.543	26.348	32.159	27.255	29.118	28.401	24.505	19.412
140	28.182	28.719	24.063	25.395	24.912	31.321	25.079	25.698	24.089	22.931	17.466
150	27.808	27.893	22.748	24.535	25.119	28.97	20.227	23.016	22.24	21.248	16.121
160	27.787	27.752	25.325	28.751	26.907	29.633	22	24.665	24.955	22.339	17.423
170	28.388	27.779	25.318	25.984	22.437	26.084	17.958	22.117	22.328	20.85	16.844
180	25.964	28.133	22.283	22.929	20.976	24.947	18.407	23.534	22.946	22.299	17.629
	27.221	28.955	24.355	22.448	20.637	25.998	19.838	24.214	24.452	23.109	18.289
190	28.227	29.39	23.954	26.609	25.252	29.817	22.36	27.933	28.835	27.163	24.306
200	26.101	28.486	22.054	26.499	24.882	29.637	23.052	27.962	28.931	27.748	25.724
210	26.615	27.608	22.639	24.277	25.477	30.283	25.112	28.637	30.367	28.939	26.084
220	26.694	26.208	23.712	25.997	25.791	32.929	28.816	31.357	32.11	28.65	24.631
230	27.389	28.784	22.689	24.692	24.915	30.992	25.156	28.263	28.907	25.865	21.626
240	27.955	28.632	23.682	25.785	25.732	31.172	24.205	30.906	33.739	30.421	24.805
245	24.909	26.437	23.332	23.678	24.159	27.584	23.813	29.137	31.971	28.71	23.702
250	25.518	27.405	21.09	22.937	24.849	27.393	23.795	27.475	29.066	26.6	20.619
255	27.053	26.744	22.024	24.519	24.155	29.119	23.451	27.534	27.506	24.288	18.173
260	26.189	27.17	21.775	24.59	24.78	29.386	23.954	27.683	26.332	22.346	17.162
265	25.849	27.094	22.93	23.502	24.231	29.086	23.055	25.944	25.639	21.376	16.22
270	25.267	28.39	21.543	24.175	23.991	28.237	23.64	26.266	25.038	22.167	16.139
275	24.856	28.347	21.106	26.504	25.384	29.375	22.337	26.059	24.616	21.646	16.196
280	26.456	26.975	21.438	25.303	25.189	30.102	23.8	26.787	25.062	22.404	16.588
285	26.164	27.48	23.639	25.474	25.411	29.131	22.734	25.962	25.632	22.795	18.006
290	27.072	27.668	22.364	25.996	24.673	30.947	25.07	27.907	28.001	24.25	18.85
300	25.551	27.69	22.914	25.724	25.753	29.423	23.308	28.289	27.824	24.221	19.96
310	25.297	27.569	23.564	23.407	24.707	28.756	25.039	28.285	29.953	26.089	21.728
320	26.615	27.014	22.188	24.47	24.26	29.32	24.178	28.224	29.434	27.29	21.554
330	27.518	26.656	23.22	23.609	23.941	28.67	23.388	28.594	27.946	26.837	21.248
340	25.648	28.168	20.89	23.378	22.649	27.933	22.172	26.808	27.776	26.527	23.187
350	25.214	25.442	19.261	24.269	23.317	28.651	21.487	26.237	27.274	25.178	23.548

Table 17. Recorded Sound Levels (dB) with Wind Speed = 13.27 m/s (2)

	Frequency									
Angle	125	157.490	198.425	250	314.980	396.850	500	629.961	793.701	1,000
0	16.911	16.013	16.516	10.993	14.911	17.212	18.166	16.724	18.691	19.692
	19.877	18.104	18.991	14.442	17.716	19.097	19.81	18.296	20.287	21.698
10	18.025	16.611	16.979	13.986	16.661	18.52	18.922	17.104	19.066	20.04
20	18.209	17.463	18.712	15.819	18.171	19.583	18.707	17.443	19.57	20.473
30	19.149	17.312	19.912	16.922	19.082	19.998	19.701	18.052	19.731	20.689
40	20.336	19.356	20.652	16.369	17.872	18.392	18.52	16.925	19.401	20.411
50	20.406	19.396	20.629	16.727	18.098	18.513	18.289	16.938	19.731	20.788
60	19.672	17.218	18.244	13.874	15.856	16.472	18.569	16.956	19.466	20.877
70	16.549	13.771	14.065	12.344	15.155	15.942	18.178	16.993	19.822	20.986
75	15.574	13.911	13.008	11.649	15.627	15.747	18.224	17.079	19.975	20.957
80	16.773	14.366	14.238	12.071	15.734	15.803	17.964	17.144	19.905	21.118
85	20.363	17.625	18.514	14.776	16.47	16.705	18.514	17.358	20.006	21.228
90	20.865	18.219	19.019	14.804	16.885	16.846	18.54	17.424	20.037	21.156
95	20.942	18.33	19.147	14.823	17.103	16.794	18.503	17.439	20.13	21.285
100	21.33	18.615	18.946	15.059	17.119	17.157	18.399	17.175	19.993	21.215
105	20.843	17.721	18.454	14.57	17.11	16.925	18.365	17.351	19.902	21.008
110	19.424	16.881	17.058	13.839	16.308	16.446	18.684	17.149	19.686	21.35
115	19.21	16.487	16.936	13.503	16.173	16.659	18.189	17.086	19.496	21.23
120	19.654	17.216	17.608	13.96	15.922	16.345	18.585	16.903	19.511	21.113
130	17.829	16.15	16.977	13.906	16.257	16.463	18.438	16.851	19.493	21.015
140	15.545	14.823	16.037	12.772	15.806	16.323	18.413	16.743	19.138	20.892
150	14.673	14.109	14.843	12.173	14.712	15.845	18.319	16.331	18.854	20.665
160	15.99	15.8	15.68	12.555	15.207	16.24	18.327	16.404	18.71	20.765
170	15.894	14.575	14.704	11.183	13.921	15.044	17.615	15.683	18.159	20.18
180	16.667	15.221	14.528	10.3	13.817	15.128	17.506	15.568	18.498	20.256
	17.252	15.183	14.968	10.794	14.913	17.222	18.846	17.266	19.886	21.045
190	22.344	21.512	22.465	16.865	17.366	18.406	19.063	17.369	19.595	20.75
200	26.095	25.073	24.474	19.363	20.415	20.954	20.184	18.68	20.273	21.25
210	25.334	25.445	28.806	22.393	21.723	21.631	20.651	18.915	20.418	21.153
220	24.46	24.398	26.279	21.156	21.524	21.576	20.004	18.403	19.668	20.69
230	21.083	21.289	23.376	19.529	21.273	21.392	19.809	17.53	19.285	20.121
240	23.656	21.52	22.529	18.666	20.285	20.036	18.848	16.666	18.43	19.272
245	22.251	19.189	20.051	16.335	18.834	18.971	17.881	16.17	17.817	19.114
250	17.498	15.27	16.431	13.292	16.949	17.238	17.75	15.578	17.565	18.875
255	15.008	12.685	13.34	10.147	15.838	16.087	17.027	15.273	17.409	18.426
260	14.082	11.098	10.938	8.321	15.022	15.701	16.904	15.194	17.049	18.497
265	12.436	9.884	9.622	7.863	14.97	15.459	16.84	15.325	16.827	18.466
270	12.745	9.953	9.513	7.393	14.939	15.476	16.983	15.193	16.965	18.509
275	13.156	9.977	9.468	7.565	14.688	15.372	16.863	15.194	16.588	18.454
280	14.065	11.222	10.687	8.243	15.355	15.202	16.47	15.356	16.742	18.841
285	14.806	12.804	12.224	9.107	15.547	15.383	16.665	15.323	16.788	18.794
290	16.293	13.794	13.93	10.04	15.287	15.671	16.952	15.323	17.121	19.076
300	18.208	16.232	16.723	12.195	15.896	15.91	17.331	15.483	17.236	19.454
310	19.441	18.165	19.201	14.843	17.272	17.397	17.587	16.174	18.363	19.984
320	19.713	18.874	19.969	15.23	17.552	17.962	18.286	16.962	19.167	20.553
330	19.312	17.882	19.112	15.071	17.251	18.095	18.627	17.078	19.317	20.659
340	19.472	18.398	19.122	15.573	18.104	19.103	19.165	17.773	19.979	21.32
350	20.617	18.16	18.929	15.727	18.475	19.381	19.701	18.235	20.325	21.443

Table 18. Recorded Sound Levels (dB) with Wind Speed = 13.27 m/s (3)

	Frequency									
Angle	1,259.921	1,587.401	2,000	2,519.842	3,174.802	4,000	5,039.684	6,349.604	8,000	10,079.368
0	20.838	24.188	27.438	29.588	28.092	26.624	23.999	22.737	24.918	21.323
	22.526	25.417	27.693	30.163	29.136	27.645	25.766	24.759	25.013	21.609
10	21.108	24.586	27.168	29.569	28.357	26.714	24.51	23.221	25.313	21.612
20	21.299	24.786	27.366	29.871	28.999	27.143	24.943	23.702	25.514	21.384
30	21.495	24.81	27.92	29.596	28.859	27.396	25.388	24.082	25.916	21.047
40	21.662	24.884	27.838	31.241	29.626	27.916	25.889	24.44	25.972	20.991
50	21.783	24.997	28.182	31.749	30.023	28.336	26.294	24.646	25.991	21.664
60	22.054	25.186	28.472	31.346	30.339	28.476	26.604	24.731	26.106	21.437
70	22.31	25.577	28.799	31.997	30.273	28.751	26.751	24.771	26.112	21.632
75	22.169	25.4	28.809	32.33	30.402	28.966	26.866	24.896	26.257	21.654
80	22.289	25.498	28.952	32.008	30.238	28.993	27.013	24.92	26.246	20.636
85	22.246	25.612	28.814	32.046	29.509	29.037	27.063	24.929	26.286	21.487
90	22.217	25.478	28.451	32.003	30.091	29.11	27.008	25.018	26.429	21.914
95	22.078	25.303	28.709	31.818	29.582	29.057	27.042	25.061	26.403	21.766
100	22.312	25.363	28.824	32.223	29.607	29.048	27.035	25.066	26.395	21.375
105	22.34	25.45	29.364	32.251	28.913	29.051	27.071	25.099	26.404	21.037
110	22.325	25.345	29.118	32.405	29.684	29.081	27.254	25.203	26.571	20.828
115	22.22	25.394	29.556	32.575	29.502	29.026	27.14	25.213	26.659	21.464
120	22.202	25.254	29.077	32.666	29.514	28.915	27.102	25.233	26.702	21.732
130	22.215	25.199	29.271	32.036	28.988	28.92	27.116	25.075	26.433	20.818
140	22.14	25.241	29.441	32.018	29.558	28.965	27.134	25.086	26.24	21.476
150	21.835	24.836	28.859	31.846	29.727	28.949	27.11	24.929	26.051	21.184
160	21.822	24.686	28.309	31.601	29.794	28.883	27.078	24.762	25.543	21.015
170	21.491	24.632	28.076	31.085	29.836	28.812	26.869	24.393	25.043	21.787
180	21.457	24.402	27.787	30.771	29.652	28.793	26.634	23.889	24.363	21.738
	22.028	25.485	29.207	31.77	29.927	29.789	27.848	25.75	24.885	20.948
190	21.664	25.326	29.062	31.603	29.87	29.603	27.747	25.363	24.56	20.771
200	22.102	25.423	28.821	31.779	29.741	29.409	27.438	24.988	24.023	21.547
210	21.997	25.182	28.752	31.688	29.578	29.295	27.1	24.536	23.621	22.422
220	21.649	24.883	28.54	31.524	29.091	28.975	26.775	24.135	23.057	22.436
230	21.014	24.117	27.764	30.837	28.266	28.564	26.191	23.753	22.752	22.01
240	20.491	23.705	27.104	30.825	28.187	28.117	25.803	23.597	22.797	22.485
245	20.298	23.53	27.34	30.615	28.147	27.921	25.623	23.429	22.733	22.53
250	20.193	23.246	26.779	30.281	28.114	27.902	25.458	23.297	22.655	22.394
255	20.164	23.07	27.062	29.932	27.123	27.666	25.1	23.183	22.559	22.607
260	19.912	22.941	26.155	29.679	27.636	27.563	24.979	23.082	22.542	23.101
265	19.986	22.818	26.009	29.158	27.515	27.371	24.927	23.081	22.561	22.704
270	19.961	22.914	25.552	29.298	28.038	27.436	24.824	23.033	22.625	22.84
275	20.052	22.901	25.892	29.222	27.459	27.266	24.801	23.025	22.523	22.693
280	20.132	22.529	25.954	29.036	27.959	27.098	24.778	23.161	22.592	21.779
285	20.247	22.538	25.891	29.398	28.145	27.213	24.713	23.197	22.675	21.942
290	20.541	22.584	26.177	29.374	28.281	27.09	24.701	23.089	22.68	22.229
300	20.408	22.493	25.964	29.018	28.516	27.103	24.576	23.06	22.648	22.176
310	20.701	22.986	26.307	29.661	28.619	27.173	24.691	23.17	22.73	22.719
320	21.267	23.697	26.625	29.582	28.724	27.039	24.786	23.238	22.909	22.282
330	21.491	24.178	27.3	28.347	28.306	26.956	24.756	23.359	23.359	22.445
340	22.132	24.653	26.94	29.221	28.945	27.268	24.869	23.457	23.601	22.565
350	22.577	25.235	27.125	29.625	28.997	27.377	25.435	24.169	24.463	21.74

Appendix B. Recorded Sound Level Plots

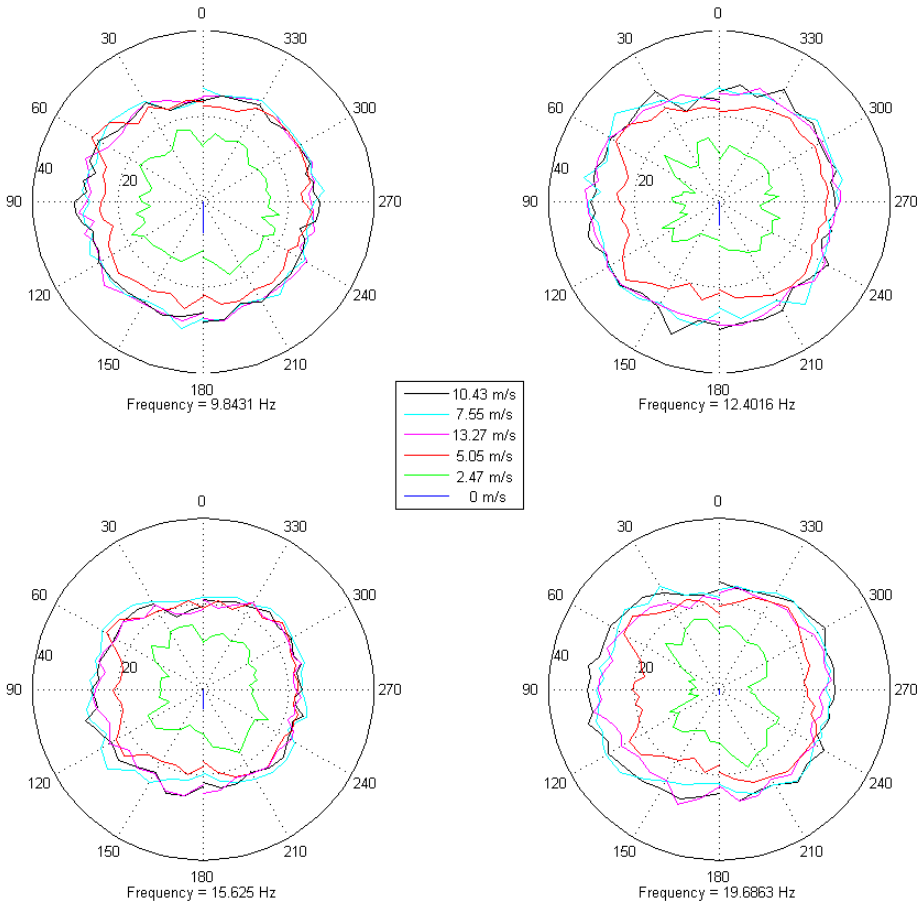


Figure 7. Noise Level (in dB) Plotted Against Head Angle for Frequencies 9.8431, 12.4016, 15.625, and 19.6863 Hz

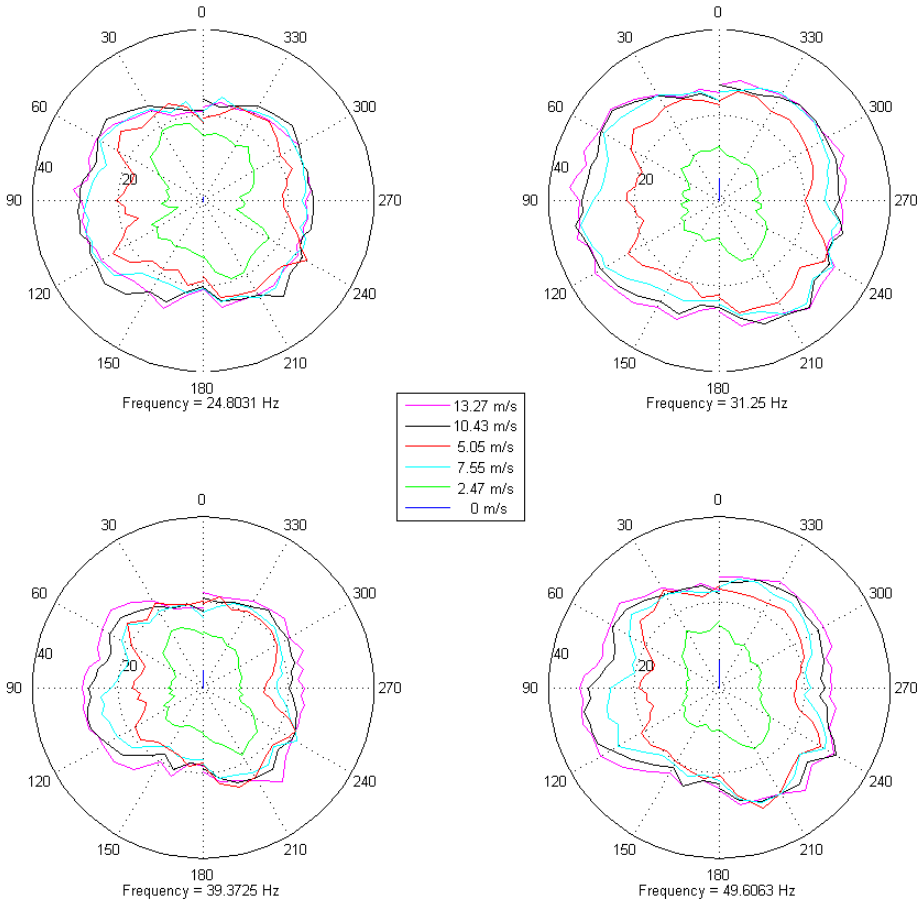


Figure 8. Noise Level (in dB) Plotted Against Head Angle for Frequencies 24.8031, 31.25, 39.3725, and 49.6063 Hz

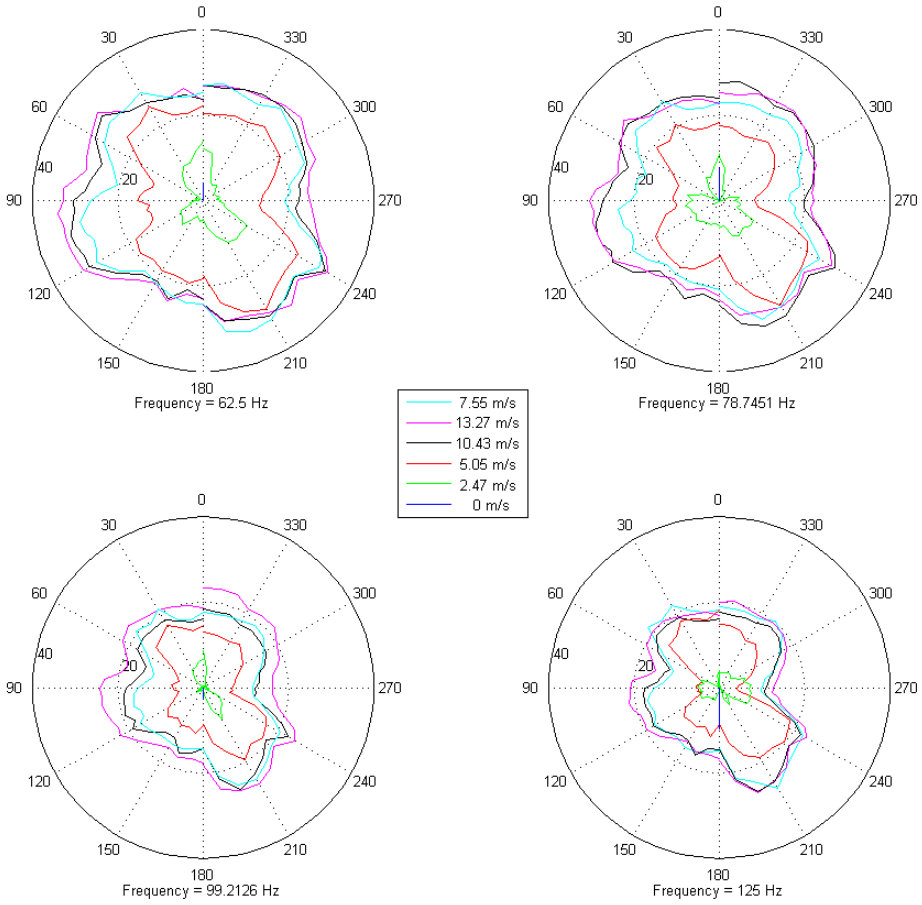


Figure 9. Noise Level (in dB) Plotted Against Head Angle for Frequencies 62.5, 78.7451, 99.2126, and 125 Hz

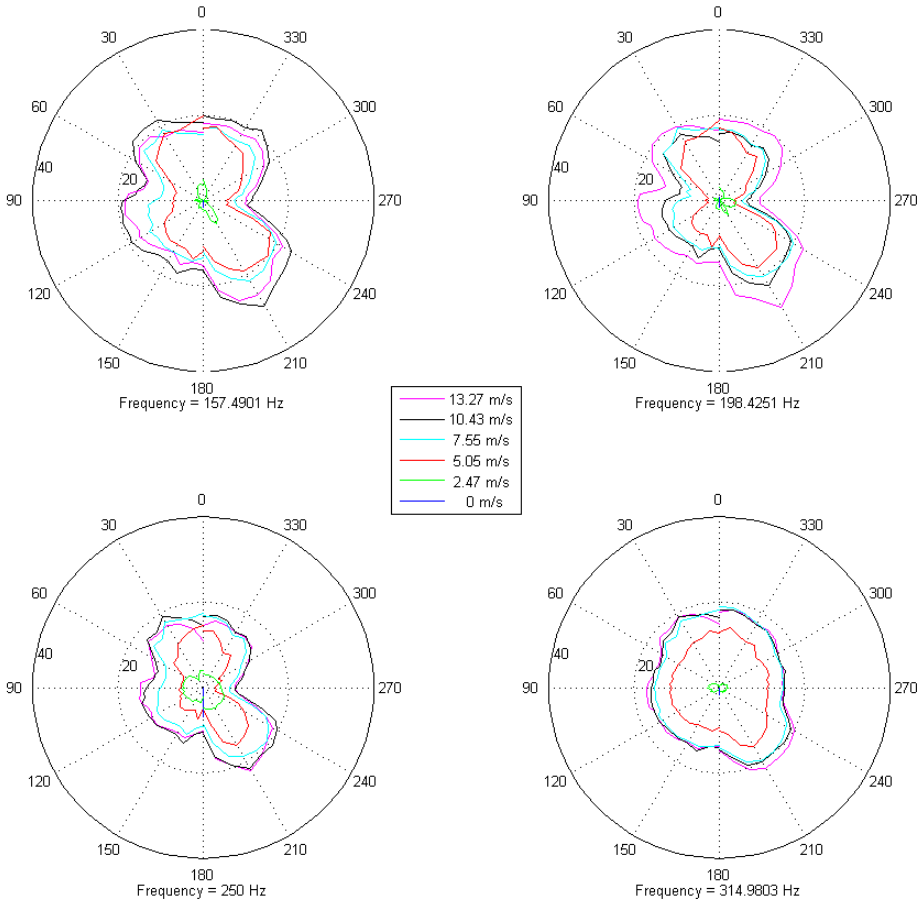


Figure 10. Noise Level (in dB) Plotted Against Head Angle for Frequencies 157.4901, 198.4251, 250, and 314.9803 Hz

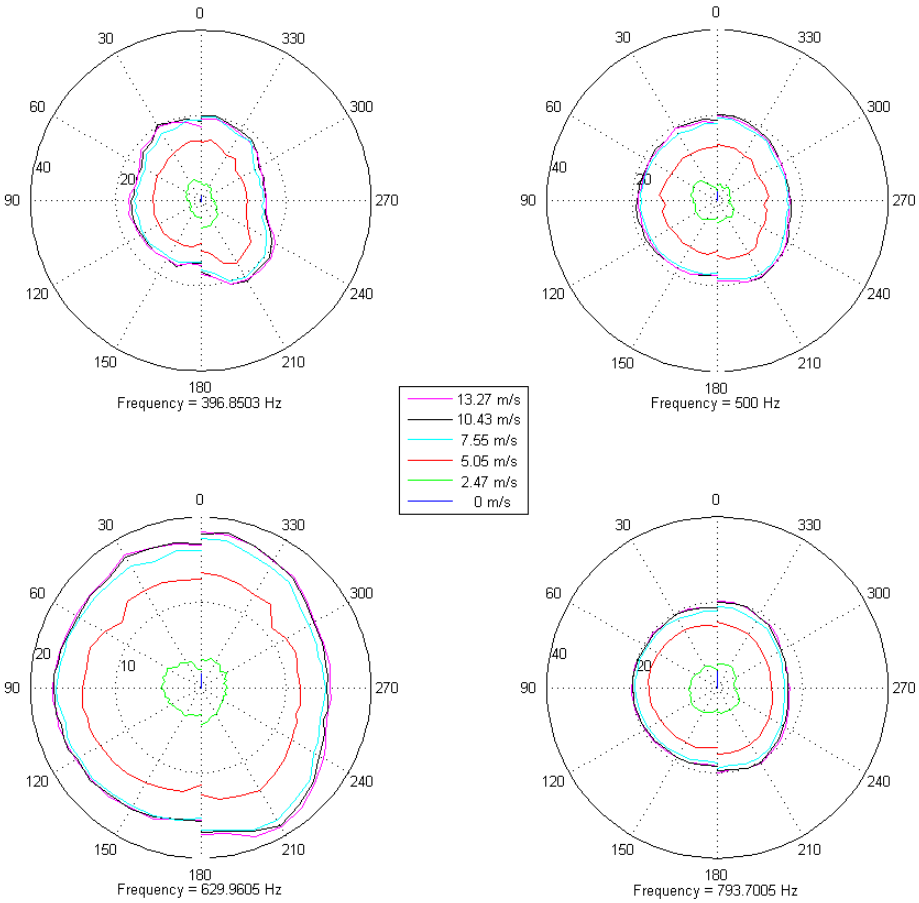


Figure 11. Noise Level (in dB) Plotted Against Head Angle for Frequencies 396.8503, 500, 629.9605, and 793.7005 Hz

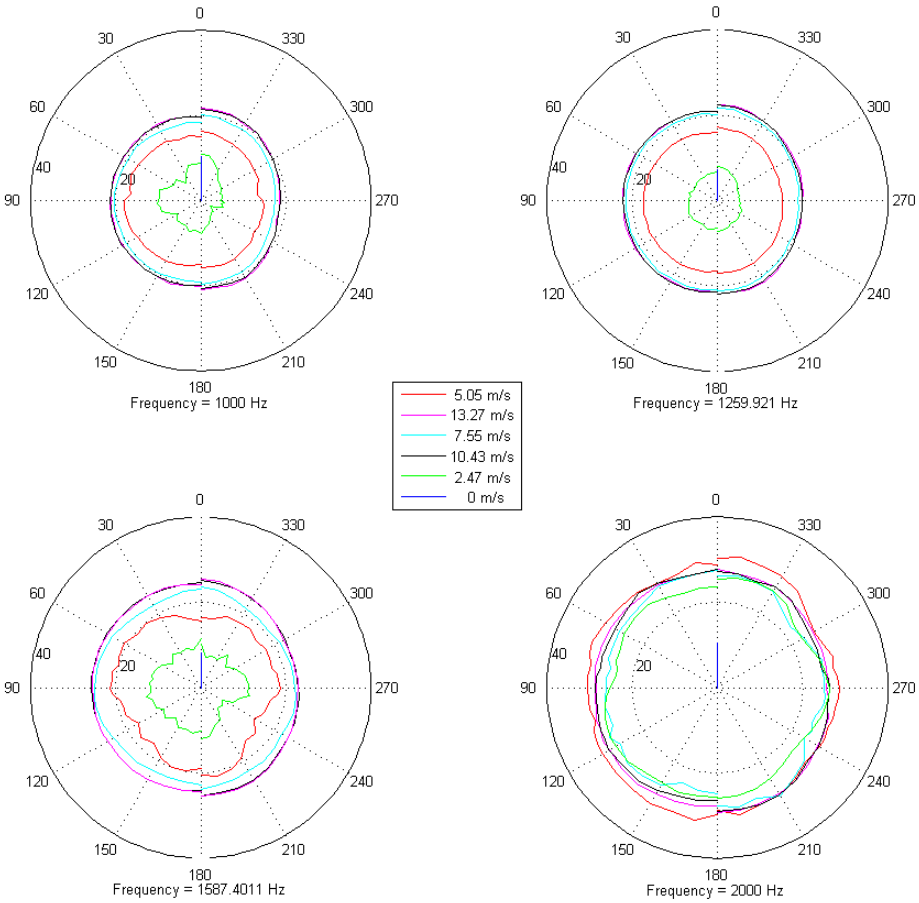


Figure 12. Noise Level (in dB) Plotted Against Head Angle for Frequencies 1,000, 1,259.921, 1,587.4011, and 2,000 Hz

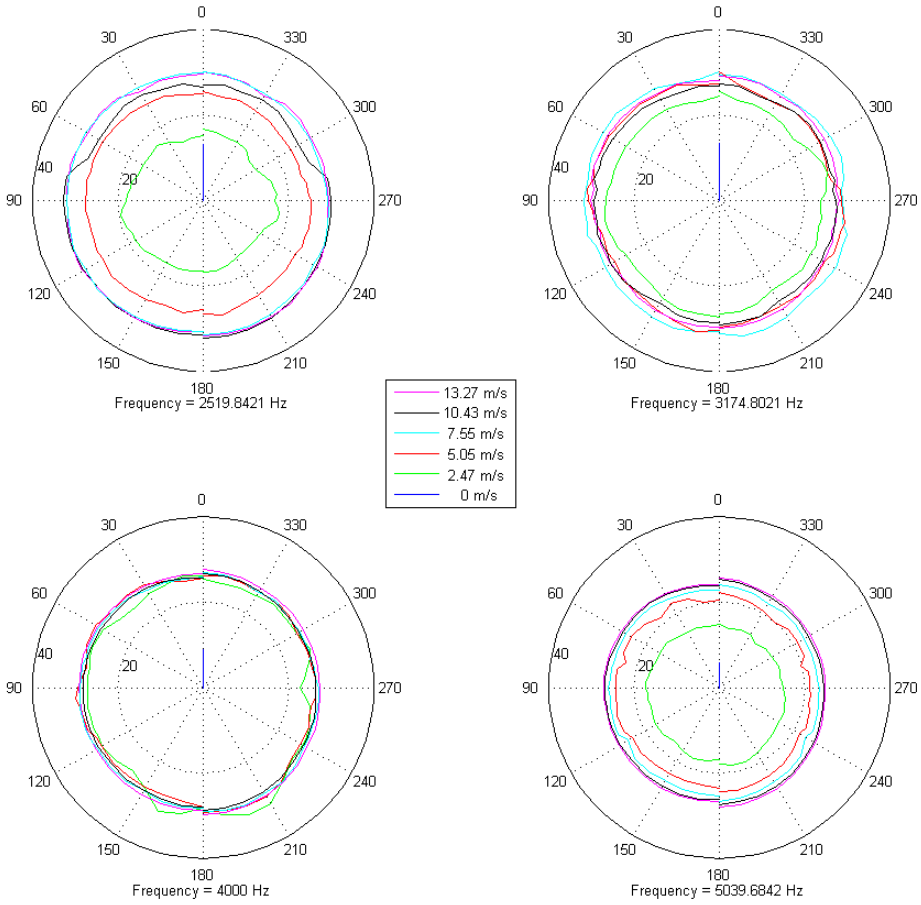


Figure 13. Noise Level (in dB) Plotted Against Head Angle for Frequencies 2,519.8421, 3,174.8021, 4,000, and 5,039.6842 Hz

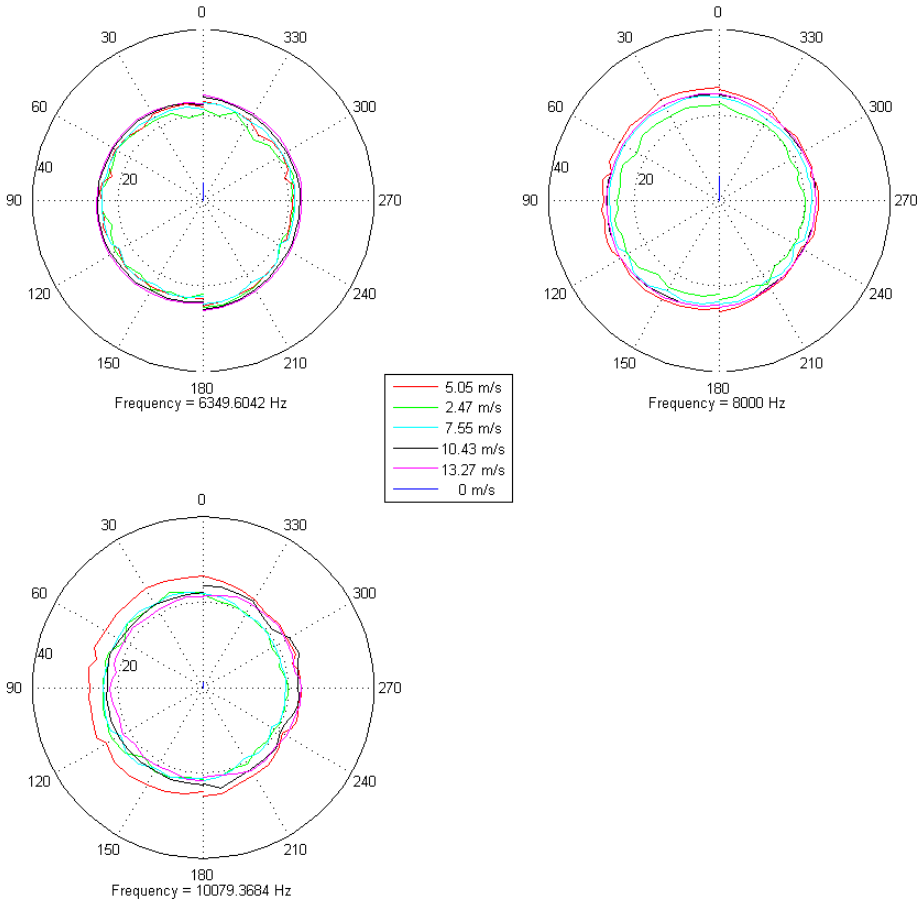


Figure 14. Noise Level (in dB) Plotted Against Head Angle for Frequencies 6,349.6042, 8,000, and 10,079.3684 Hz

Appendix C. Comparison of Predicted Noise Levels and Recorded Levels

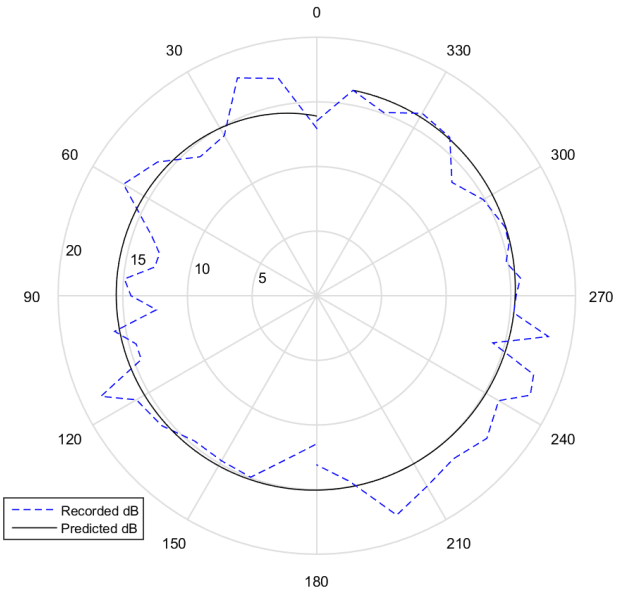


Figure 15. Comparison of Predicted and Recorded Noise Levels for Frequency = 9.8431 Hz, Wind Speed = 2.47 m/s

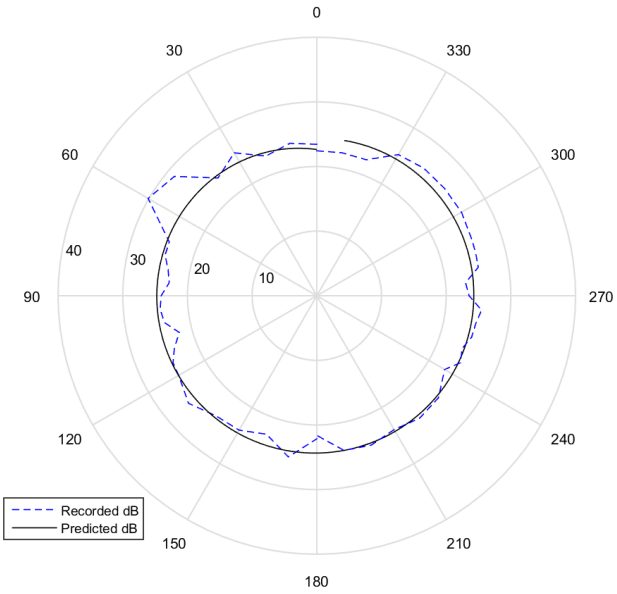


Figure 16. Comparison of Predicted and Recorded Noise Levels for Frequency = 9.8431 Hz, Wind Speed = 5.05 m/s

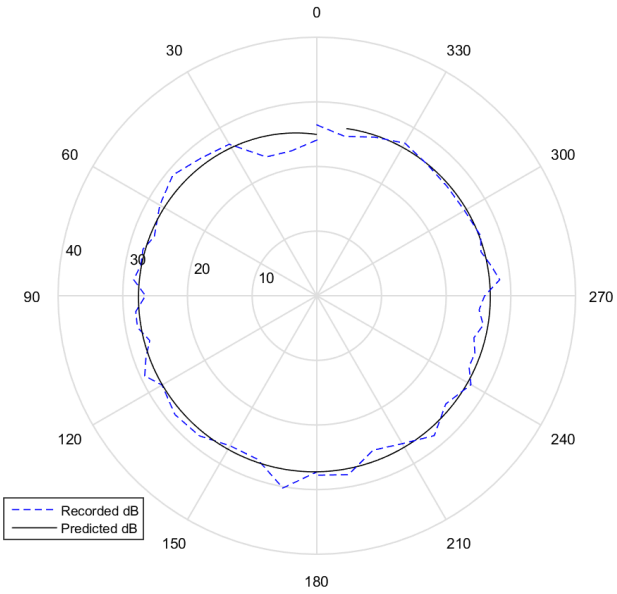


Figure 17. Comparison of Predicted and Recorded Noise Levels for Frequency = 9.8431 Hz, Wind Speed = 7.55 m/s

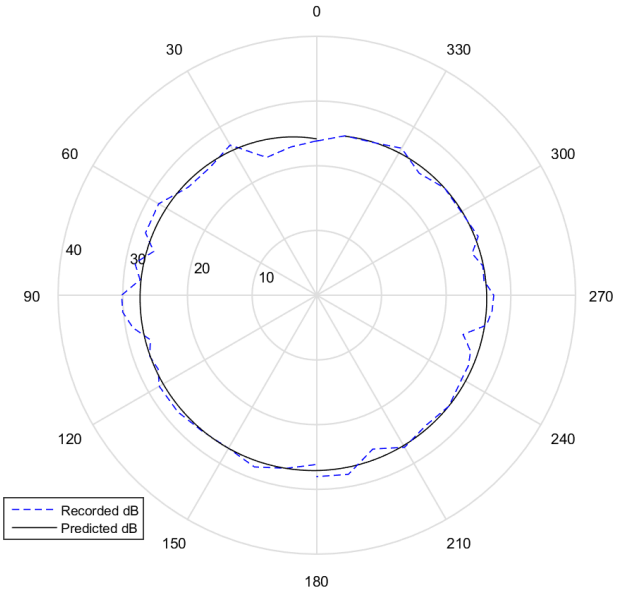


Figure 18. Comparison of Predicted and Recorded Noise Levels for Frequency = 9.8431 Hz, Wind Speed = 10.43 m/s

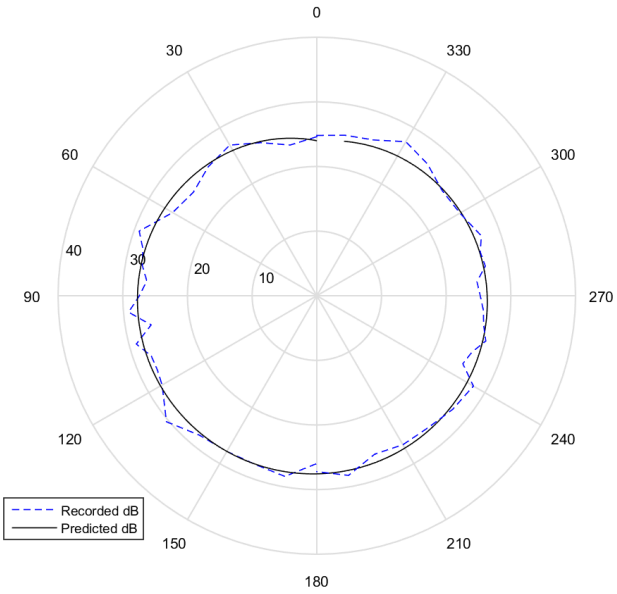


Figure 19. Comparison of Predicted and Recorded Noise Levels for Frequency = 9.8431 Hz, Wind Speed = 13.27 m/s

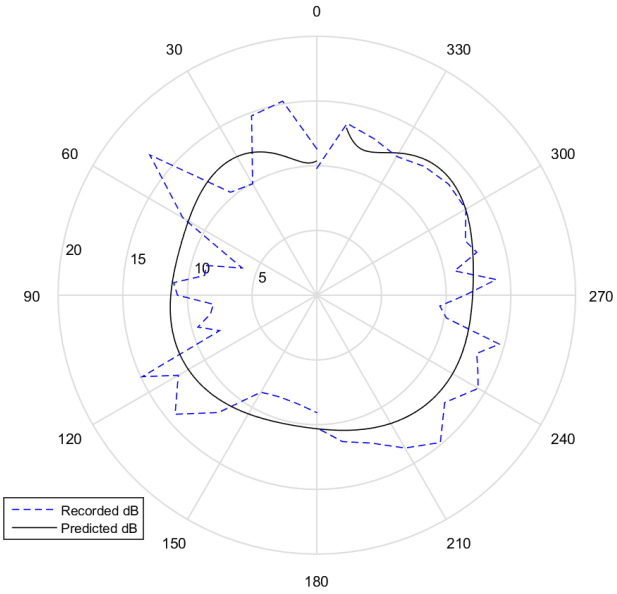


Figure 20. Comparison of Predicted and Recorded Noise Levels for Frequency = 12.4016 Hz, Wind Speed = 2.47 m/s

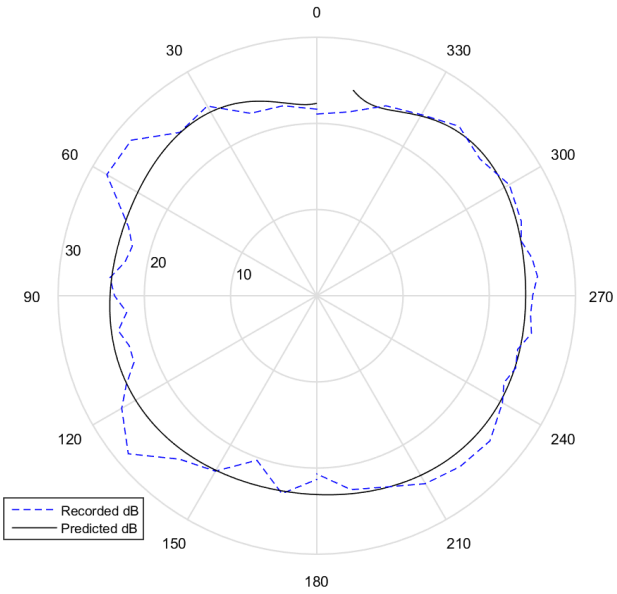


Figure 21. Comparison of Predicted and Recorded Noise Levels for Frequency = 12.4016 Hz, Wind Speed = 5.05 m/s

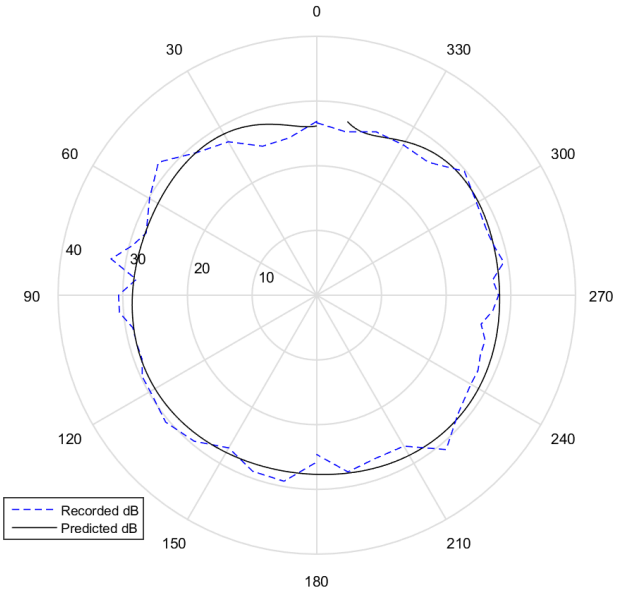


Figure 22. Comparison of Predicted and Recorded Noise Levels for Frequency = 12.4016 Hz, Wind Speed = 7.55 m/s

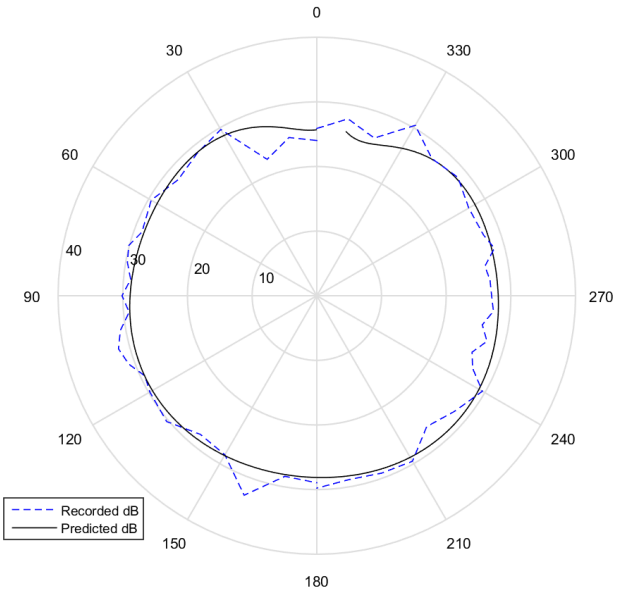


Figure 23. Comparison of Predicted and Recorded Noise Levels for Frequency = 12.4016 Hz, Wind Speed = 10.43 m/s

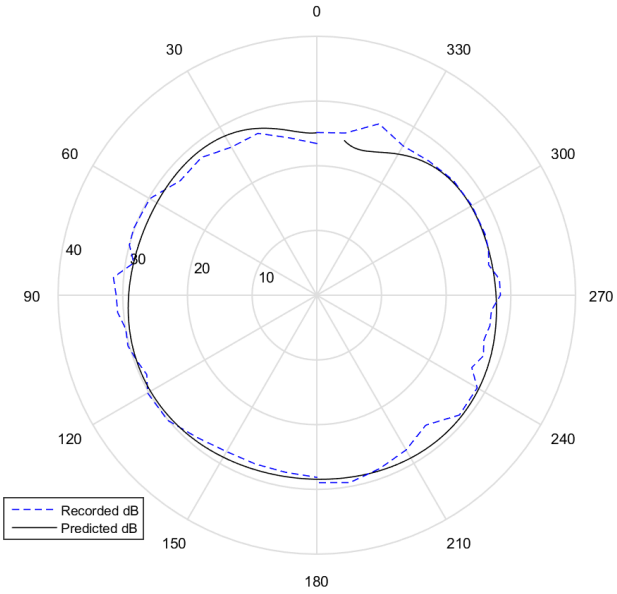


Figure 24. Comparison of Predicted and Recorded Noise Levels for Frequency = 12.4016 Hz, Wind Speed = 13.27 m/s

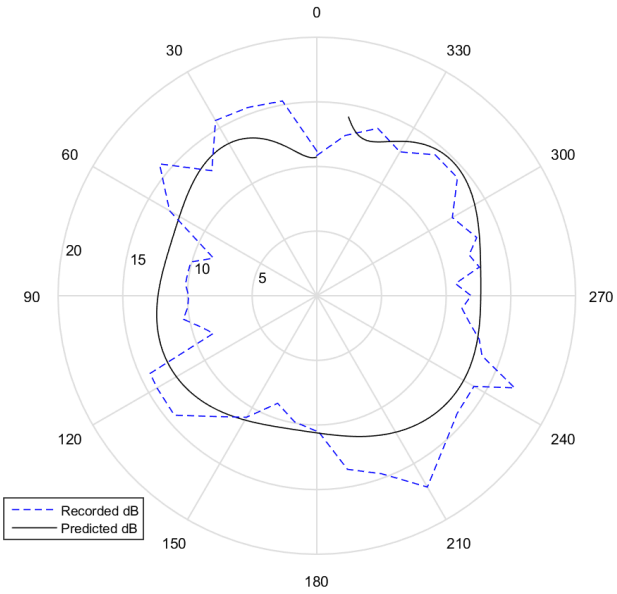


Figure 25. Comparison of Predicted and Recorded Noise Levels for Frequency = 15.625 Hz, Wind Speed = 2.47 m/s

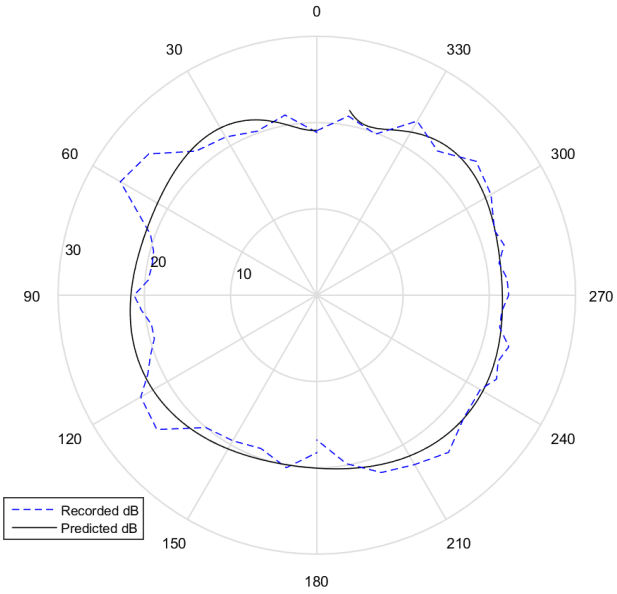


Figure 26. Comparison of Predicted and Recorded Noise Levels for Frequency = 15.625 Hz, Wind Speed = 5.05 m/s

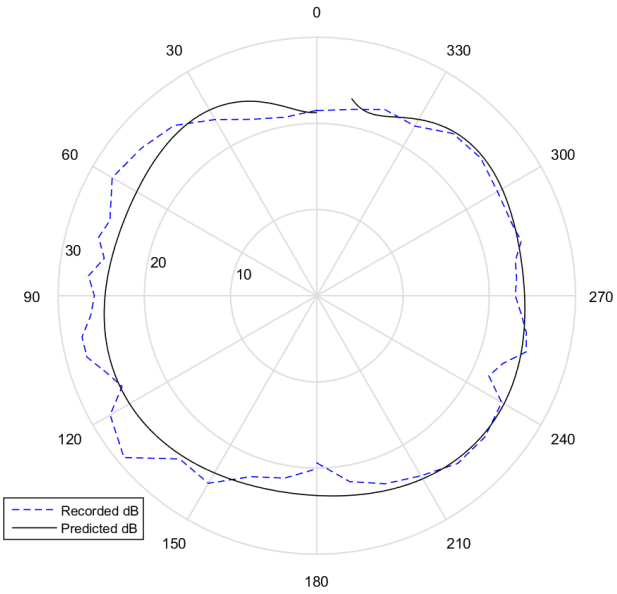


Figure 27. Comparison of Predicted and Recorded Noise Levels for Frequency = 15.625 Hz, Wind Speed = 7.55 m/s

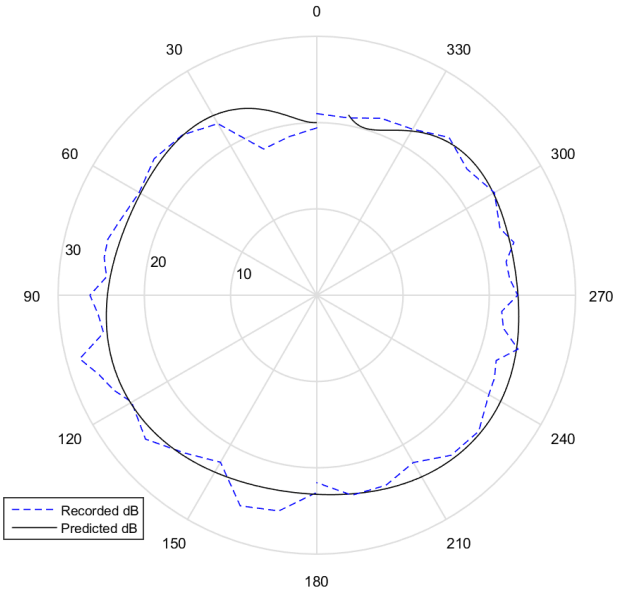


Figure 28. Comparison of Predicted and Recorded Noise Levels for Frequency = 15.625 Hz, Wind Speed = 10.43 m/s

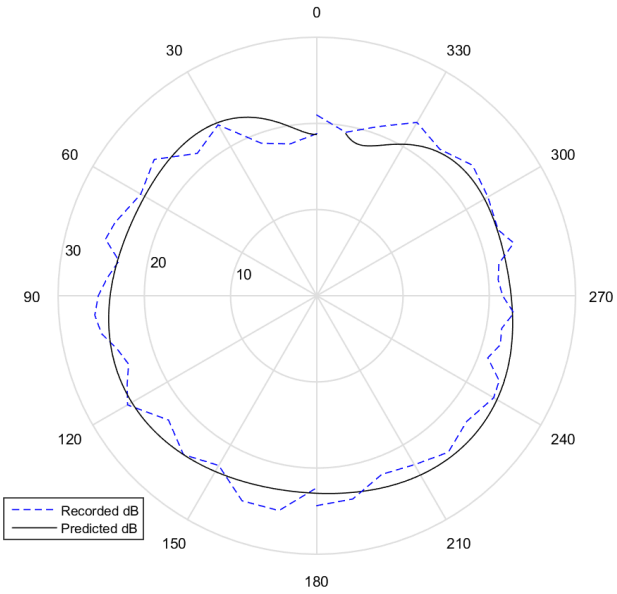


Figure 29. Comparison of Predicted and Recorded Noise Levels for Frequency = 15.625 Hz, Wind Speed = 13.27 m/s

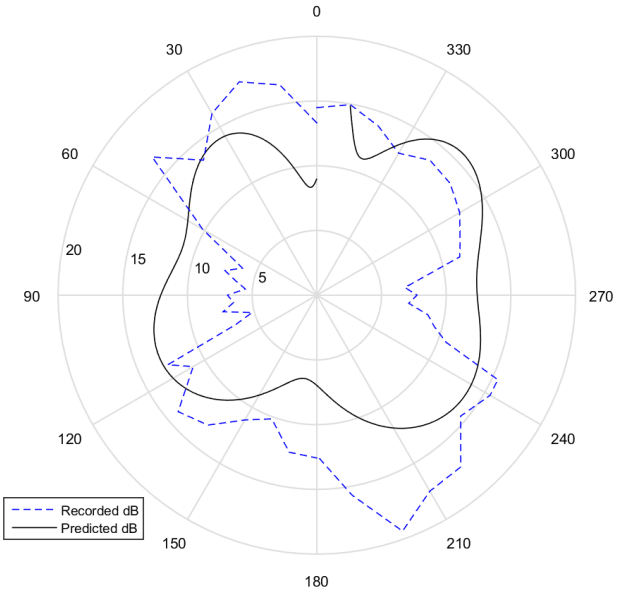


Figure 30. Comparison of Predicted and Recorded Noise Levels for Frequency = 19.6863 Hz, Wind Speed = 2.47 m/s

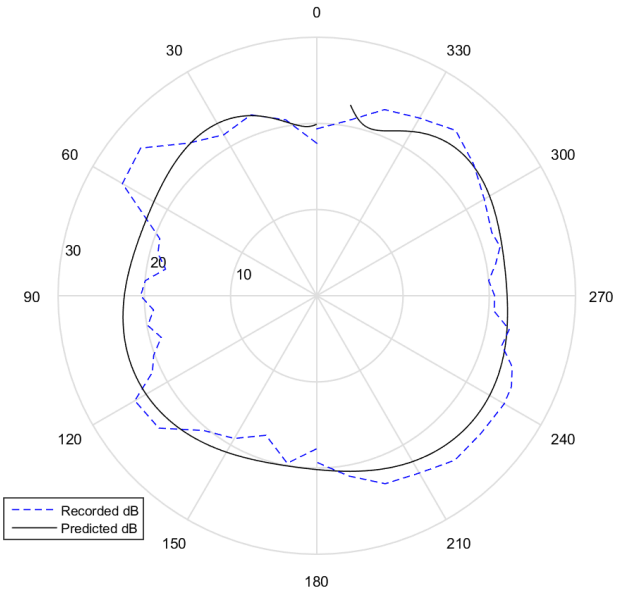


Figure 31. Comparison of Predicted and Recorded Noise Levels for Frequency = 19.6863 Hz, Wind Speed = 5.05 m/s

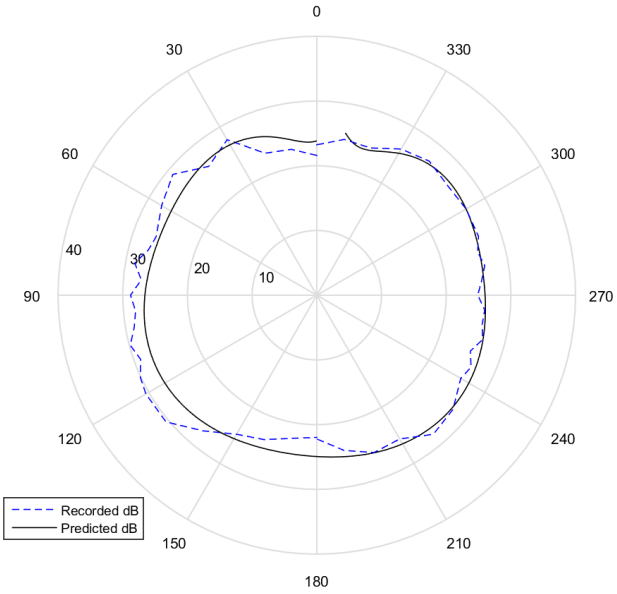


Figure 32. Comparison of Predicted and Recorded Noise Levels for Frequency = 19.6863 Hz, Wind Speed = 7.55 m/s

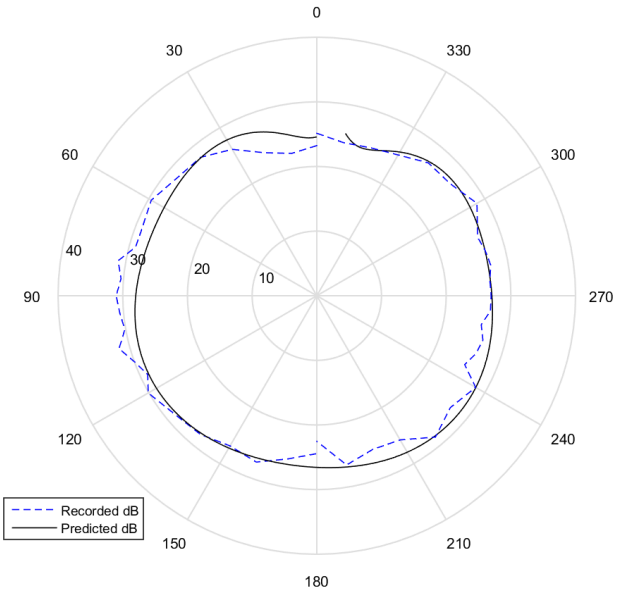


Figure 33. Comparison of Predicted and Recorded Noise Levels for Frequency = 19.6863 Hz, Wind Speed = 10.43 m/s

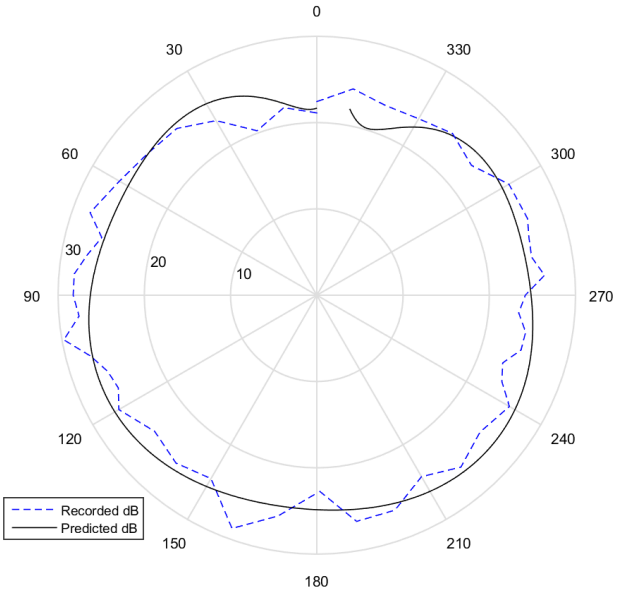


Figure 34. Comparison of Predicted and Recorded Noise Levels for Frequency = 19.6863 Hz, Wind Speed = 13.27 m/s

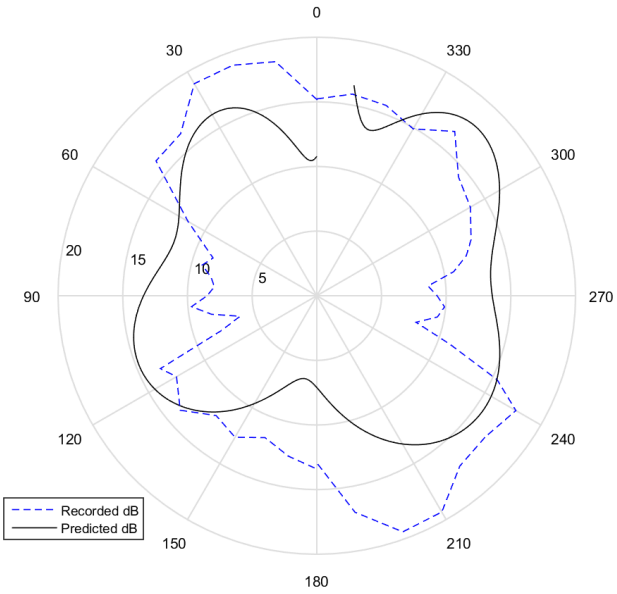


Figure 35. Comparison of Predicted and Recorded Noise Levels for Frequency = 24.8031 Hz, Wind Speed = 2.47 m/s

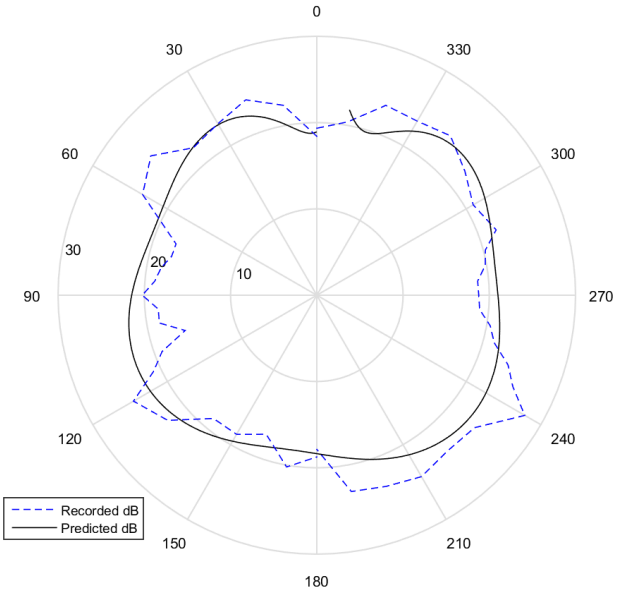


Figure 36. Comparison of Predicted and Recorded Noise Levels for Frequency = 24.8031 Hz, Wind Speed = 5.05 m/s

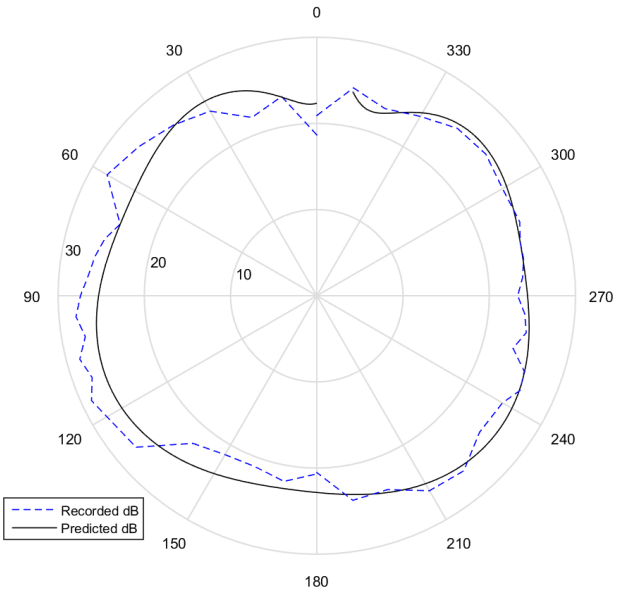


Figure 37. Comparison of Predicted and Recorded Noise Levels for Frequency = 24.8031 Hz, Wind Speed = 7.55 m/s

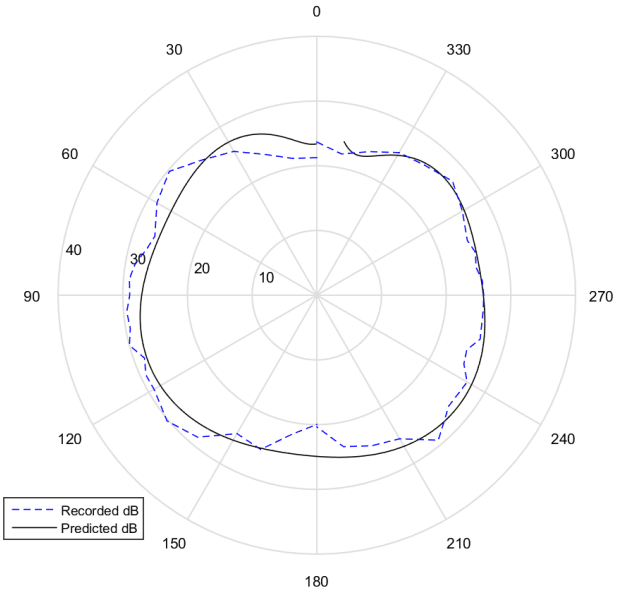


Figure 38. Comparison of Predicted and Recorded Noise Levels for Frequency = 24.8031 Hz, Wind Speed = 10.43 m/s

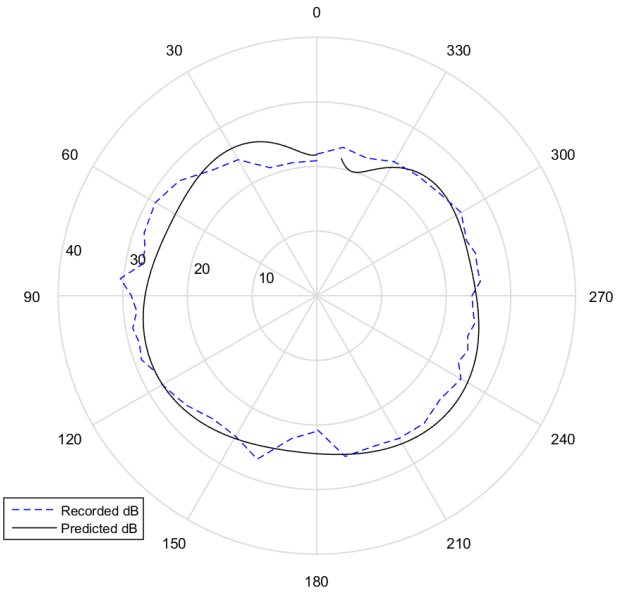


Figure 39. Comparison of Predicted and Recorded Noise Levels for Frequency = 24.8031 Hz, Wind Speed = 13.27 m/s

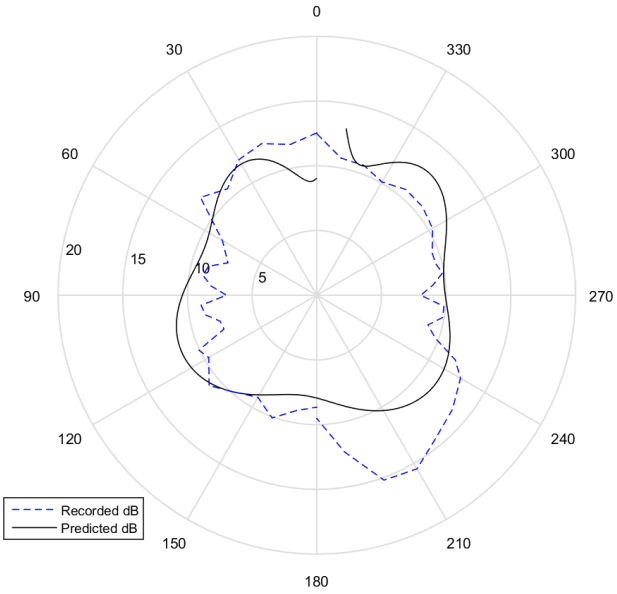


Figure 40. Comparison of Predicted and Recorded Noise Levels for Frequency = 31.25 Hz, Wind Speed = 2.47 m/s

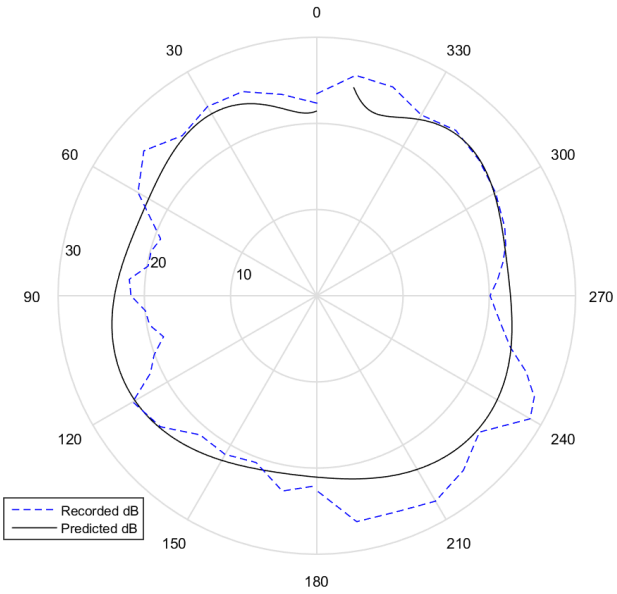


Figure 41. Comparison of Predicted and Recorded Noise Levels for Frequency = 31.25 Hz, Wind Speed = 5.05 m/s

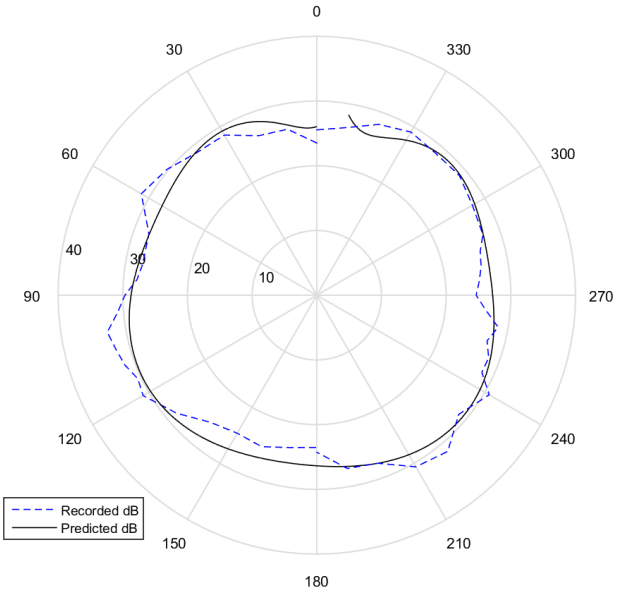


Figure 42. Comparison of Predicted and Recorded Noise Levels for Frequency = 31.25 Hz, Wind Speed = 7.55 m/s

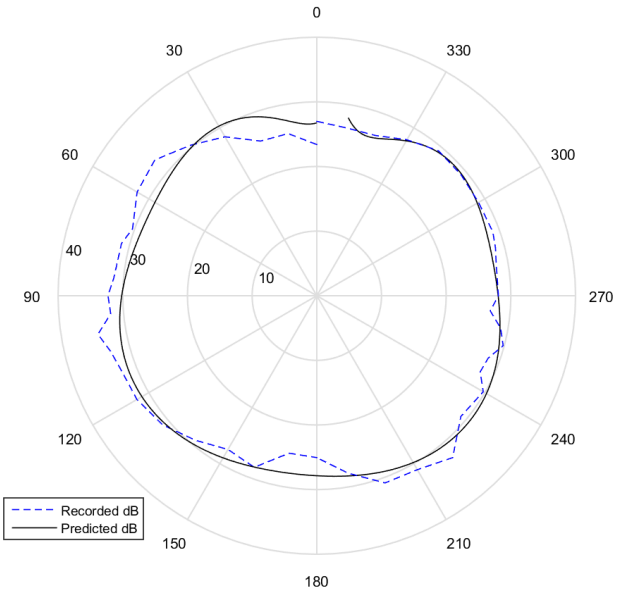


Figure 43. Comparison of Predicted and Recorded Noise Levels for Frequency = 31.25 Hz, Wind Speed = 10.43 m/s

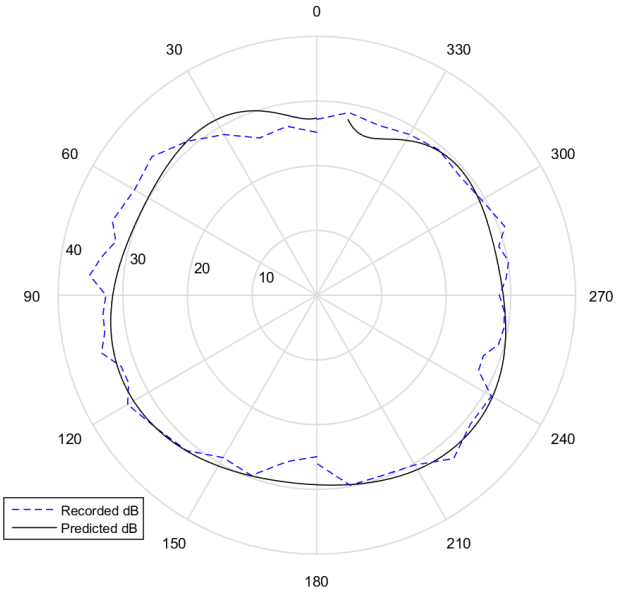


Figure 44. Comparison of Predicted and Recorded Noise Levels for Frequency = 31.25 Hz, Wind Speed = 13.27 m/s

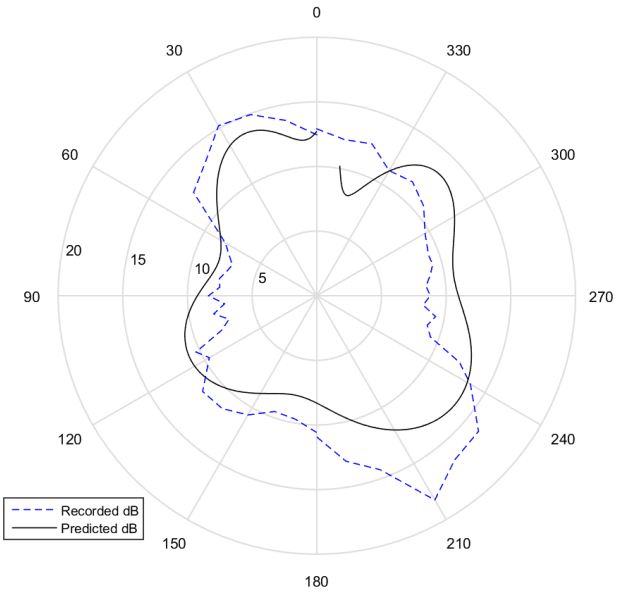


Figure 45. Comparison of Predicted and Recorded Noise Levels for Frequency = 39.3725 Hz, Wind Speed = 2.47 m/s

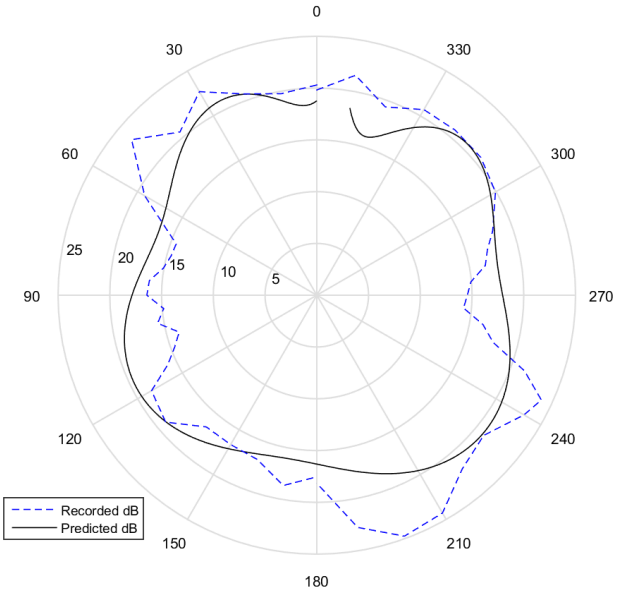


Figure 46. Comparison of Predicted and Recorded Noise Levels for Frequency = 39.3725 Hz, Wind Speed = 5.05 m/s

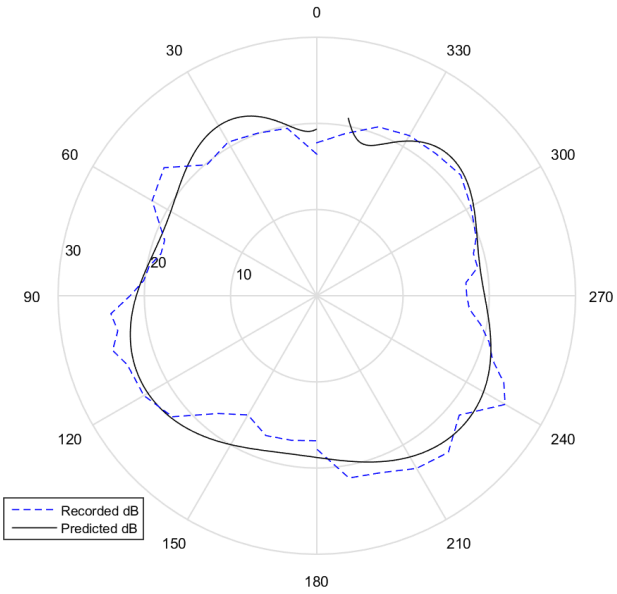


Figure 47. Comparison of Predicted and Recorded Noise Levels for Frequency = 39.3725 Hz, Wind Speed = 7.55 m/s

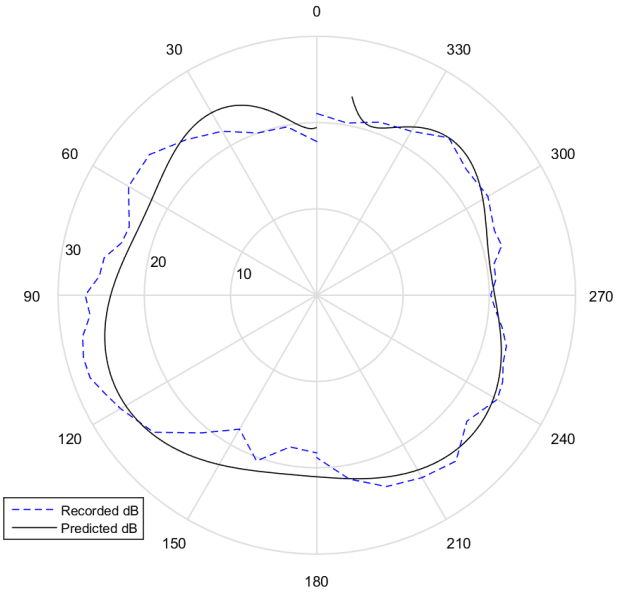


Figure 48. Comparison of Predicted and Recorded Noise Levels for Frequency = 39.3725 Hz, Wind Speed = 10.43 m/s

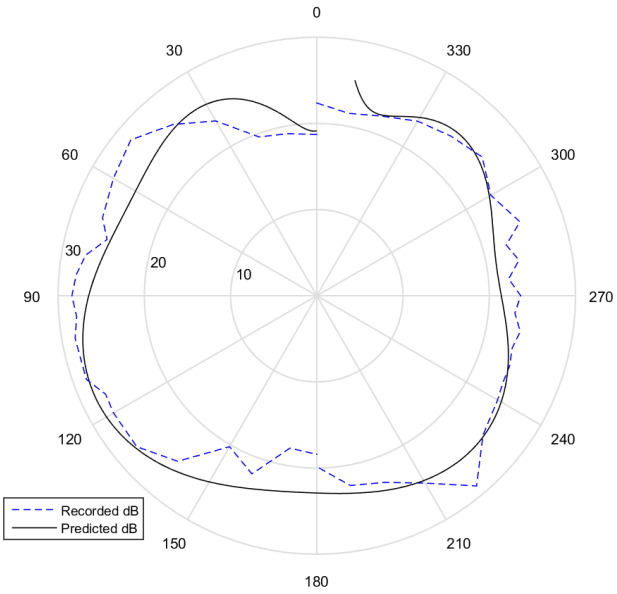


Figure 49. Comparison of Predicted and Recorded Noise Levels for Frequency = 39.3725 Hz, Wind Speed = 13.27 m/s

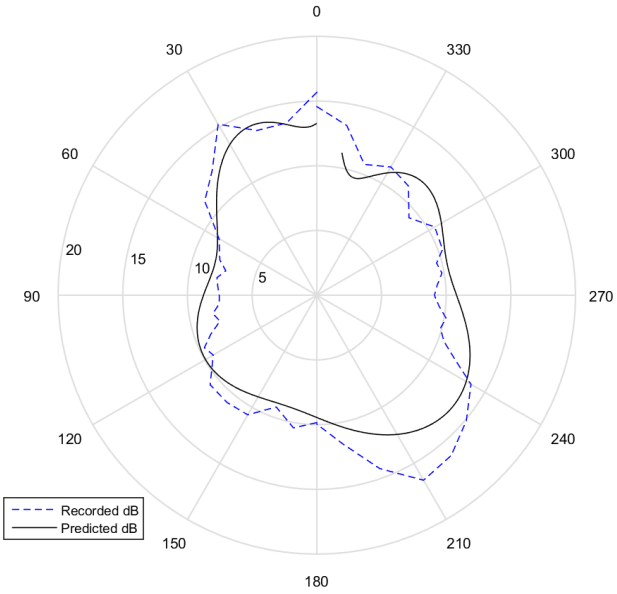


Figure 50. Comparison of Predicted and Recorded Noise Levels for Frequency = 49.6063 Hz, Wind Speed = 2.47 m/s

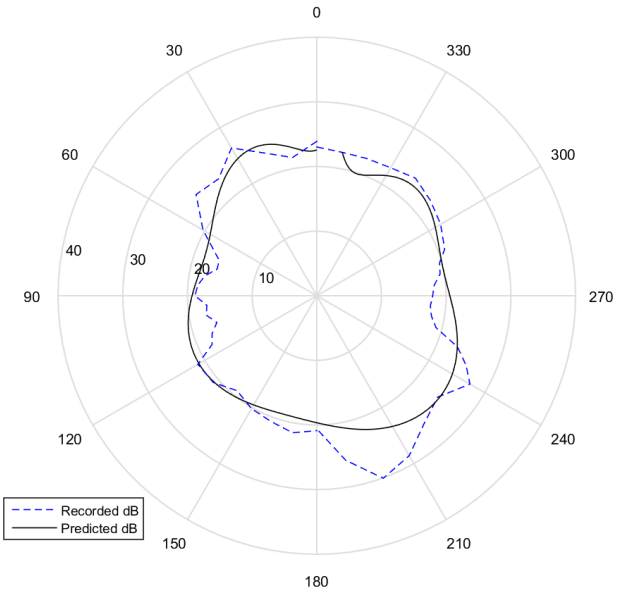


Figure 51. Comparison of Predicted and Recorded Noise Levels for Frequency = 49.6063 Hz, Wind Speed = 5.05 m/s

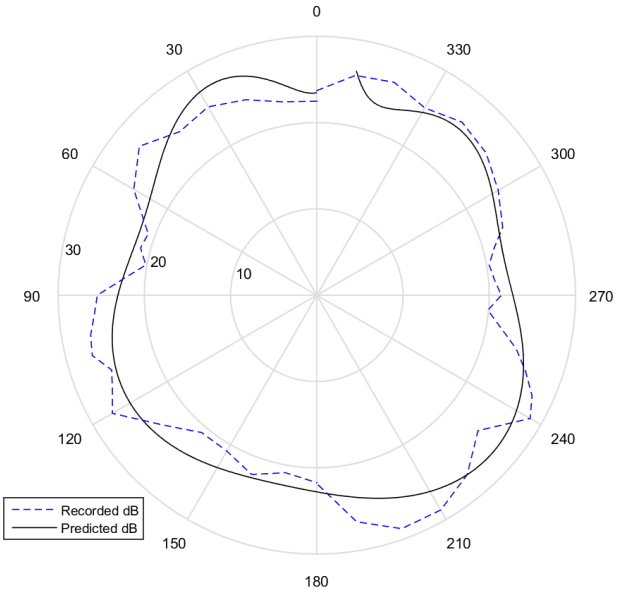


Figure 52. Comparison of Predicted and Recorded Noise Levels for Frequency = 49.6063 Hz, Wind Speed = 7.55 m/s

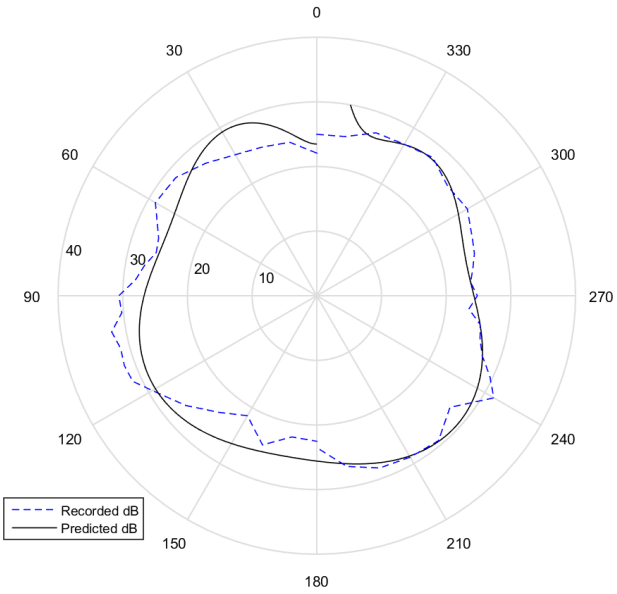


Figure 53. Comparison of Predicted and Recorded Noise Levels for Frequency = 49.6063 Hz, Wind Speed = 10.43 m/s

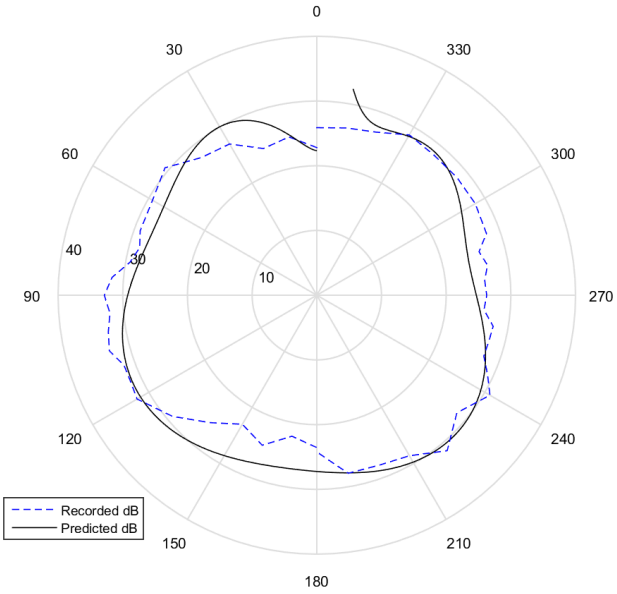


Figure 54. Comparison of Predicted and Recorded Noise Levels for Frequency = 49.6063 Hz, Wind Speed = 13.27 m/s

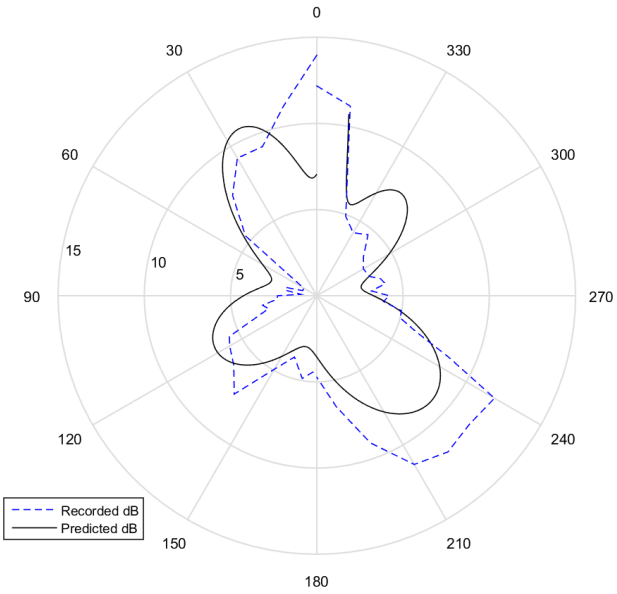


Figure 55. Comparison of Predicted and Recorded Noise Levels for Frequency = 62.5 Hz, Wind Speed = 2.47 m/s

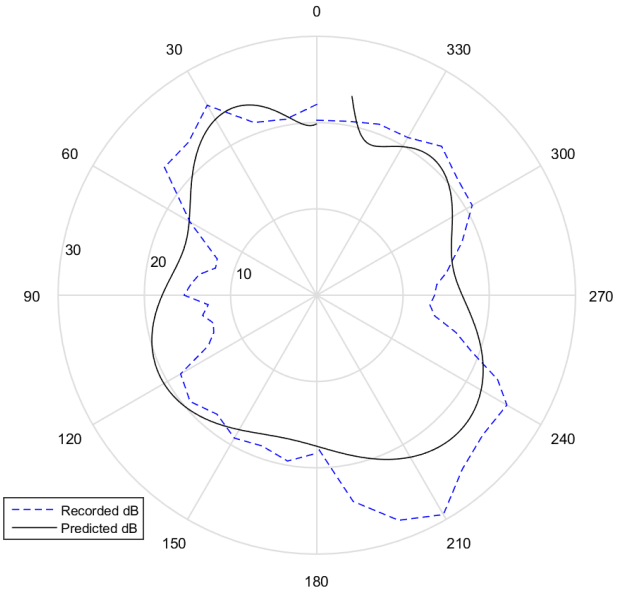


Figure 56. Comparison of Predicted and Recorded Noise Levels for Frequency = 62.5 Hz, Wind Speed = 5.05 m/s

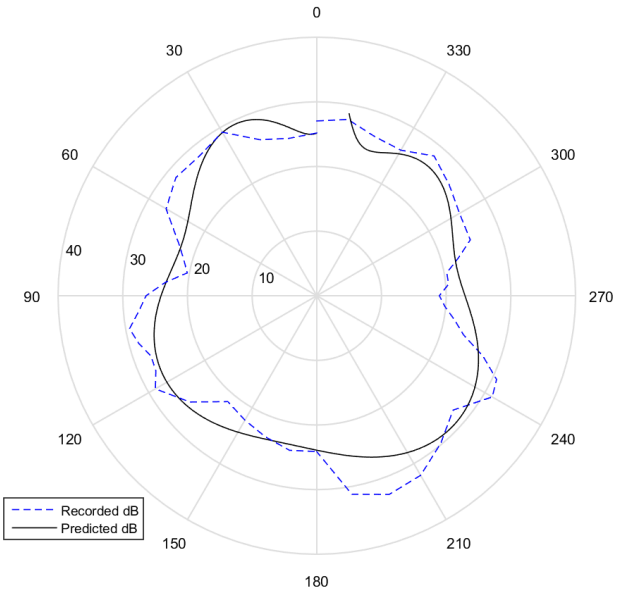


Figure 57. Comparison of Predicted and Recorded Noise Levels for Frequency = 62.5 Hz, Wind Speed = 7.55 m/s

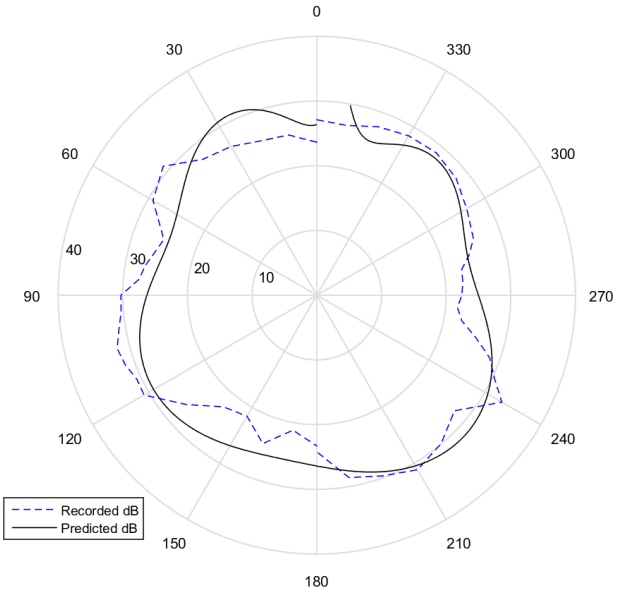


Figure 58. Comparison of Predicted and Recorded Noise Levels for Frequency = 62.5 Hz, Wind Speed = 10.43 m/s

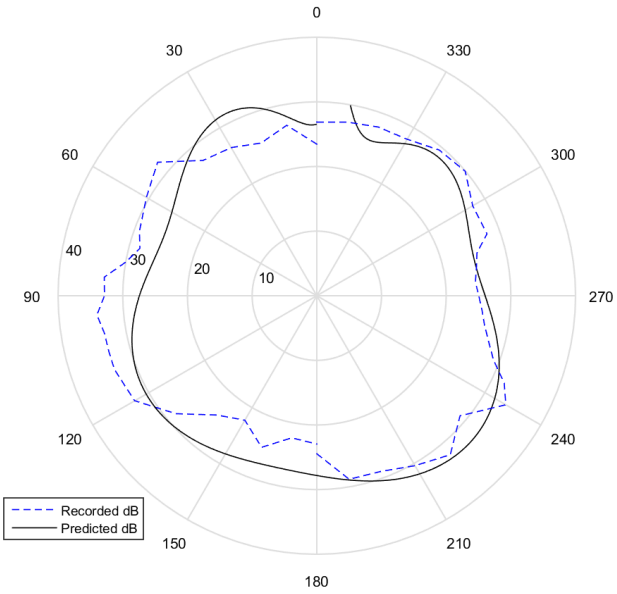


Figure 59. Comparison of Predicted and Recorded Noise Levels for Frequency = 62.5 Hz, Wind Speed = 13.27 m/s

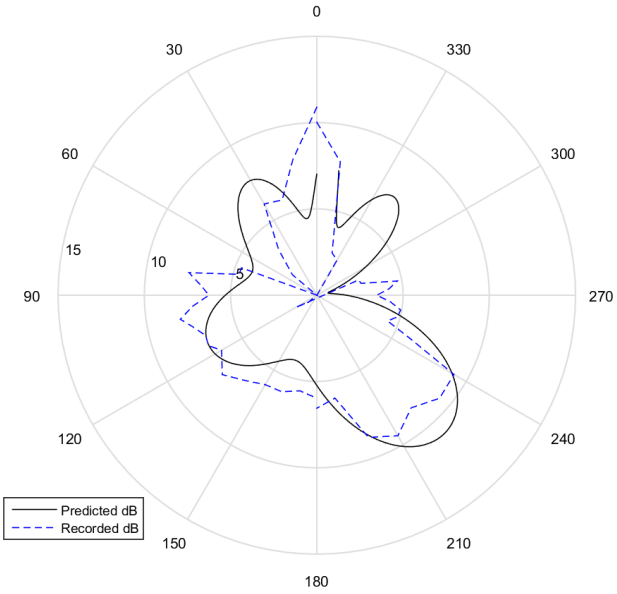


Figure 60. Comparison of Predicted and Recorded Noise Levels for Frequency = 78.7451 Hz, Wind Speed = 2.47 m/s

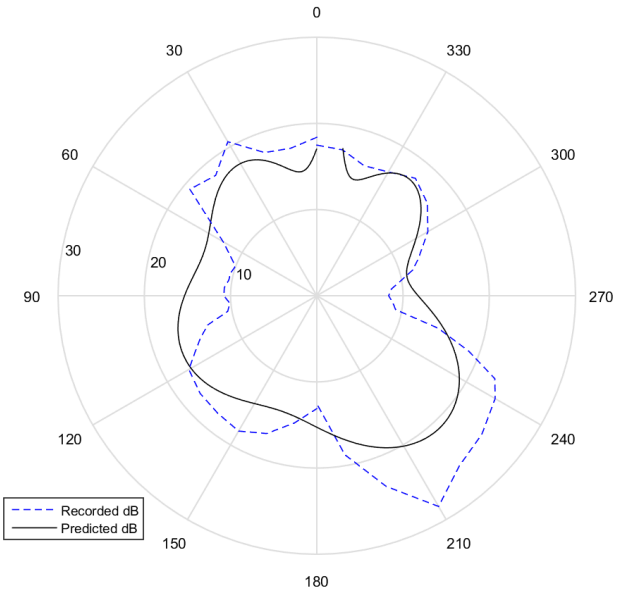


Figure 61. Comparison of Predicted and Recorded Noise Levels for Frequency = 78.7451 Hz, Wind Speed = 5.05 m/s

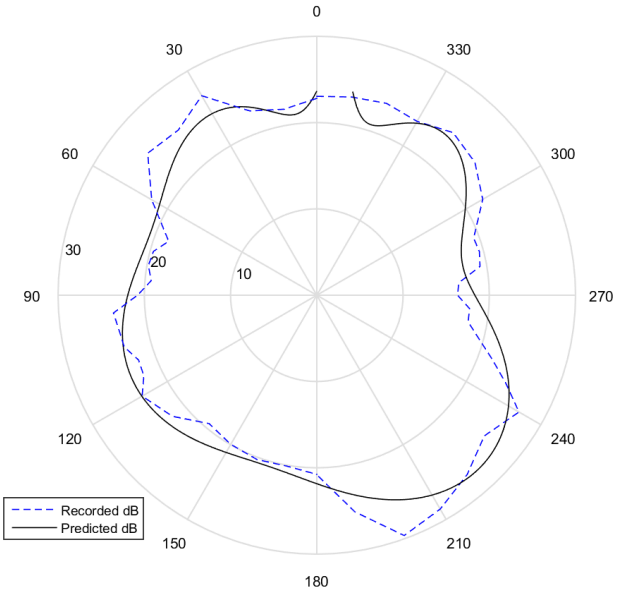


Figure 62. Comparison of Predicted and Recorded Noise Levels for Frequency = 78.7451 Hz, Wind Speed = 7.55 m/s

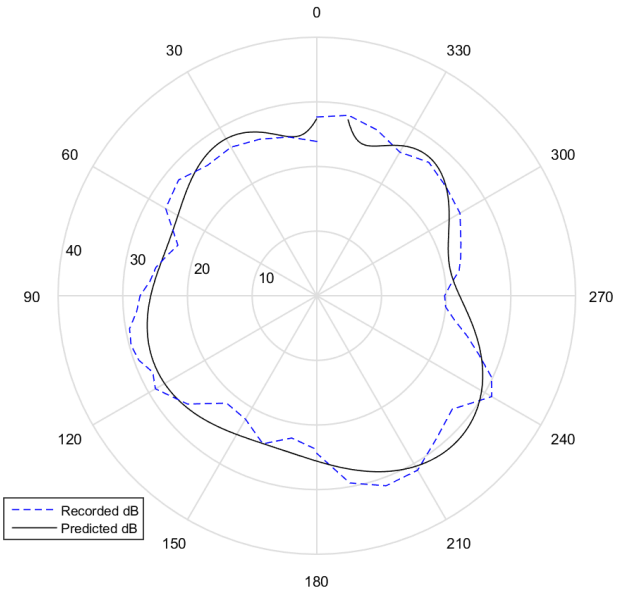


Figure 63. Comparison of Predicted and Recorded Noise Levels for Frequency = 78.7451 Hz, Wind Speed = 10.43 m/s

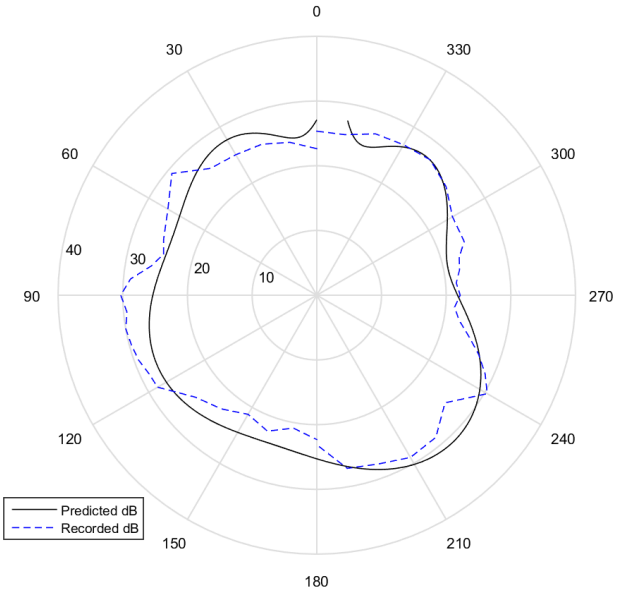


Figure 64. Comparison of Predicted and Recorded Noise Levels for Frequency = 78.7451 Hz, Wind Speed = 13.27 m/s

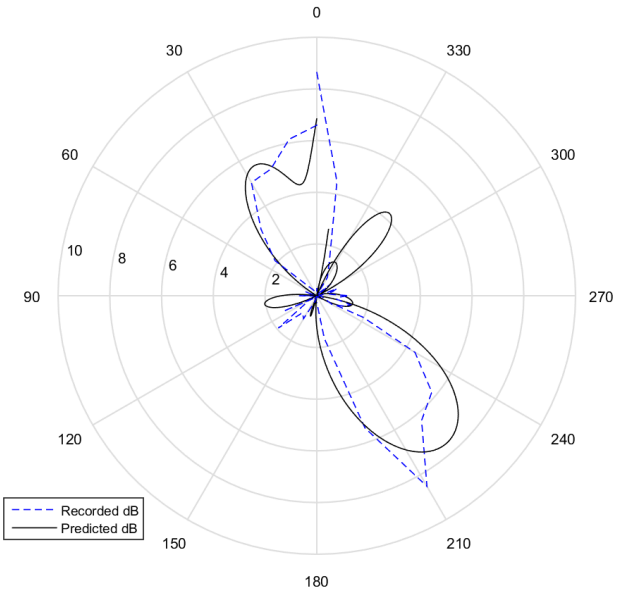


Figure 65. Comparison of Predicted and Recorded Noise Levels for Frequency = 99.2126 Hz, Wind Speed = 2.47 m/s

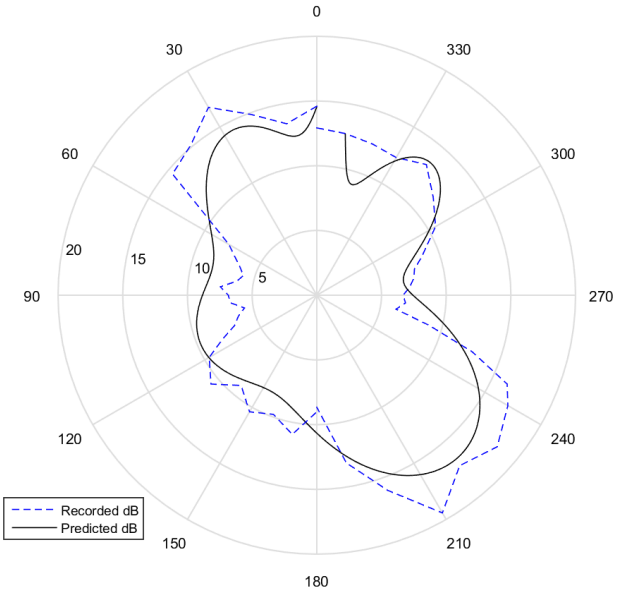


Figure 66. Comparison of Predicted and Recorded Noise Levels for Frequency = 99.2126 Hz, Wind Speed = 5.05 m/s

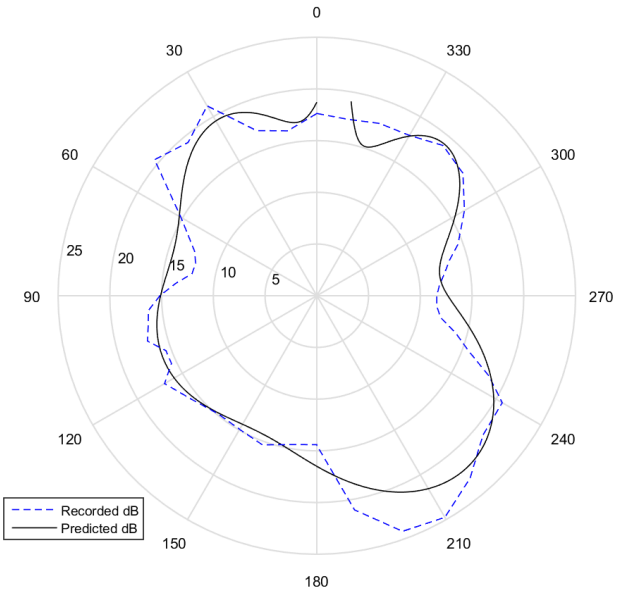


Figure 67. Comparison of Predicted and Recorded Noise Levels for Frequency = 99.2126 Hz, Wind Speed = 7.55 m/s

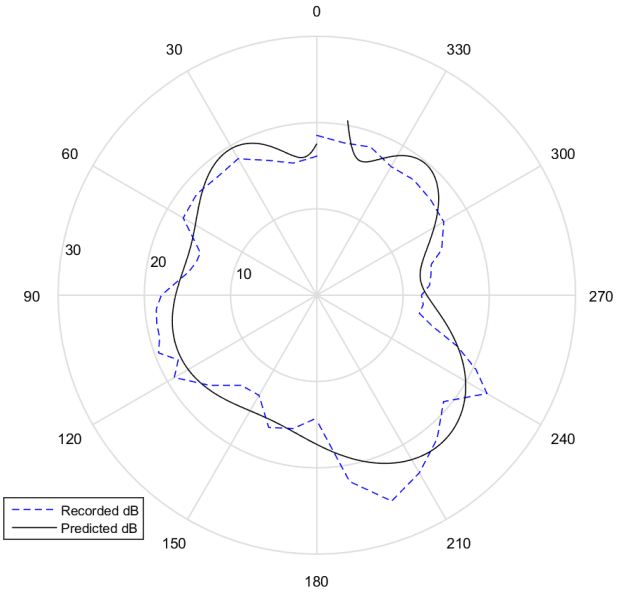


Figure 68. Comparison of Predicted and Recorded Noise Levels for Frequency = 99.2126 Hz, Wind Speed = 10.43 m/s

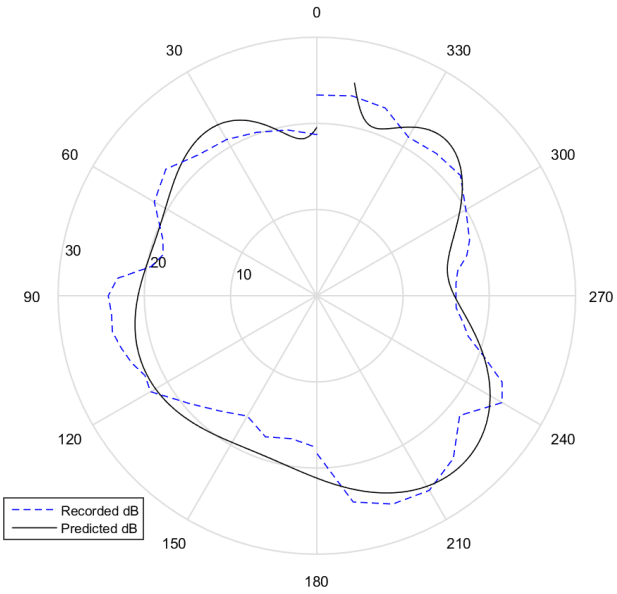


Figure 69. Comparison of Predicted and Recorded Noise Levels for Frequency = 99.2126 Hz, Wind Speed = 13.27 m/s

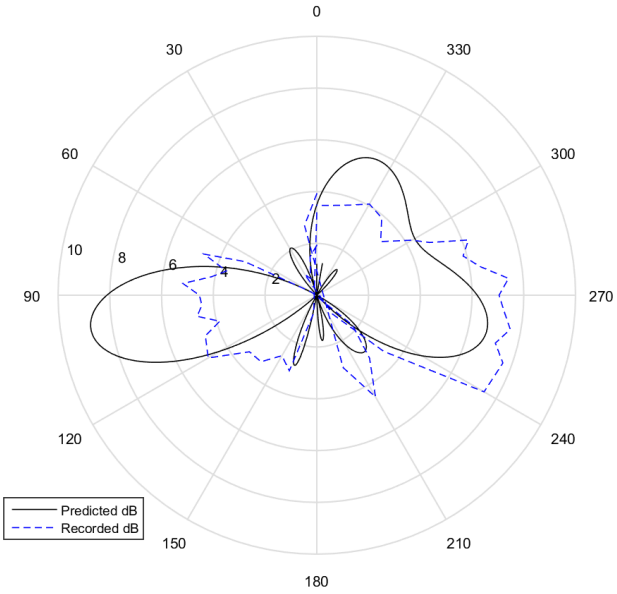


Figure 70. Comparison of Predicted and Recorded Noise Levels for Frequency = 125 Hz, Wind Speed = 2.47 m/s

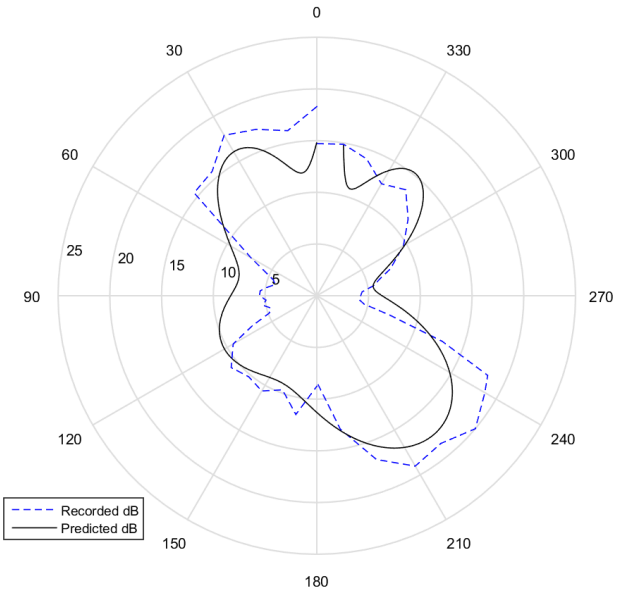


Figure 71. Comparison of Predicted and Recorded Noise Levels for Frequency = 125 Hz, Wind Speed = 5.05 m/s

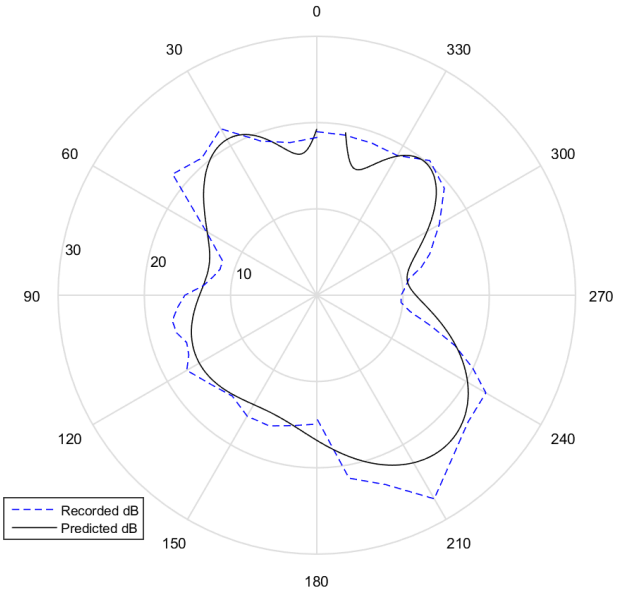


Figure 72. Comparison of Predicted and Recorded Noise Levels for Frequency = 125 Hz, Wind Speed = 7.55 m/s

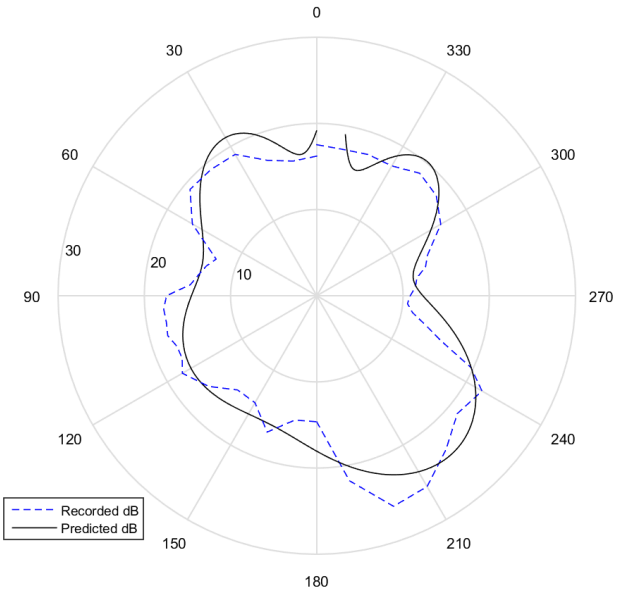


Figure 73. Comparison of Predicted and Recorded Noise Levels for Frequency = 125 Hz, Wind Speed = 10.43 m/s

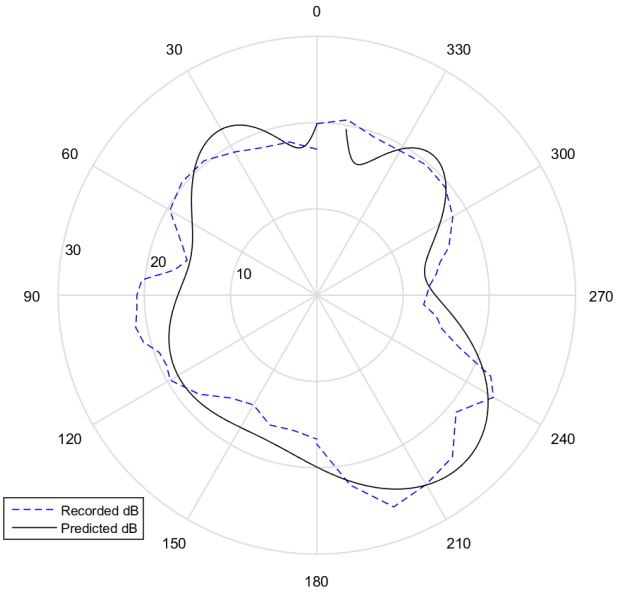


Figure 74. Comparison of Predicted and Recorded Noise Levels for Frequency = 125 Hz, Wind Speed = 13.27 m/s

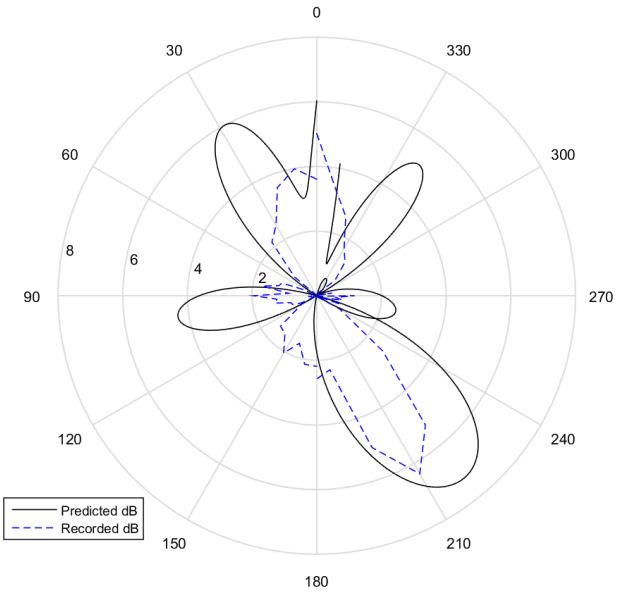


Figure 75. Comparison of Predicted and Recorded Noise Levels for Frequency = 157.4901 Hz, Wind Speed = 2.47 m/s

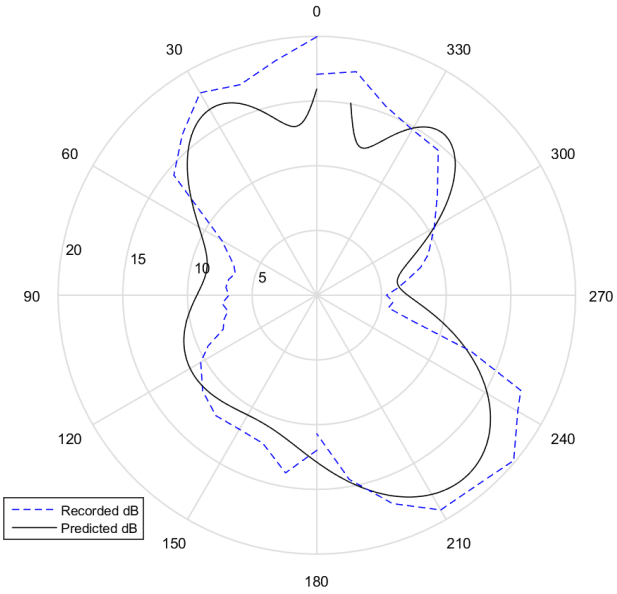


Figure 76. Comparison of Predicted and Recorded Noise Levels for Frequency = 157.4901 Hz, Wind Speed = 5.05 m/s

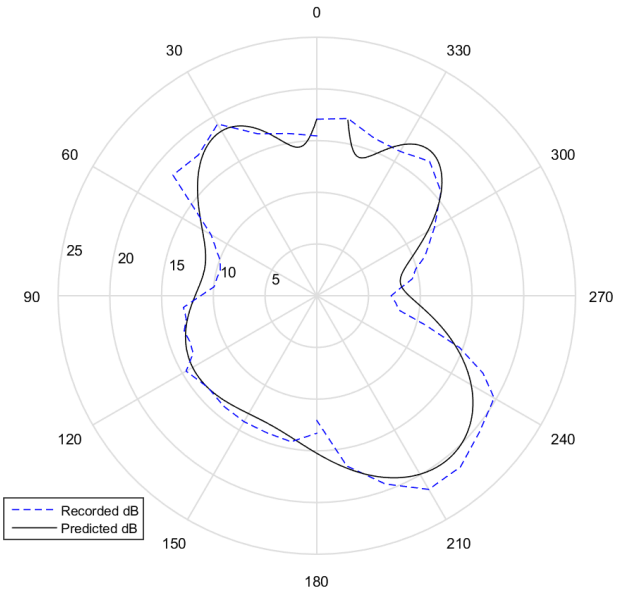


Figure 77. Comparison of Predicted and Recorded Noise Levels for Frequency = 157.4901 Hz, Wind Speed = 7.55 m/s

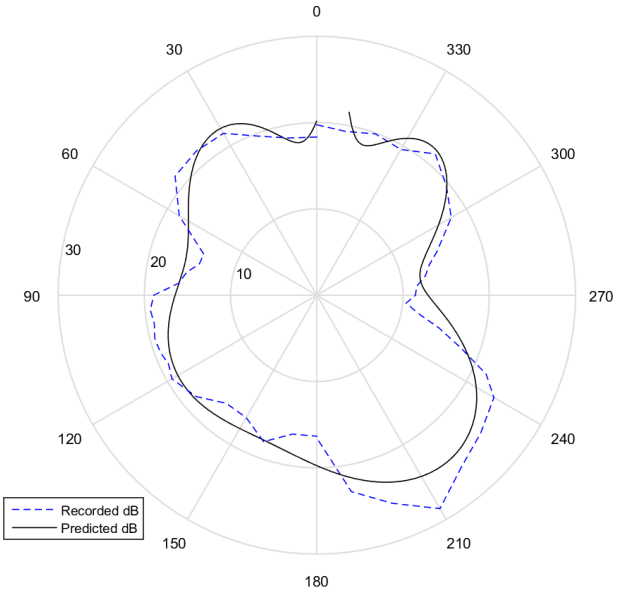


Figure 78. Comparison of Predicted and Recorded Noise Levels for Frequency = 157.4901 Hz, Wind Speed = 10.43 m/s

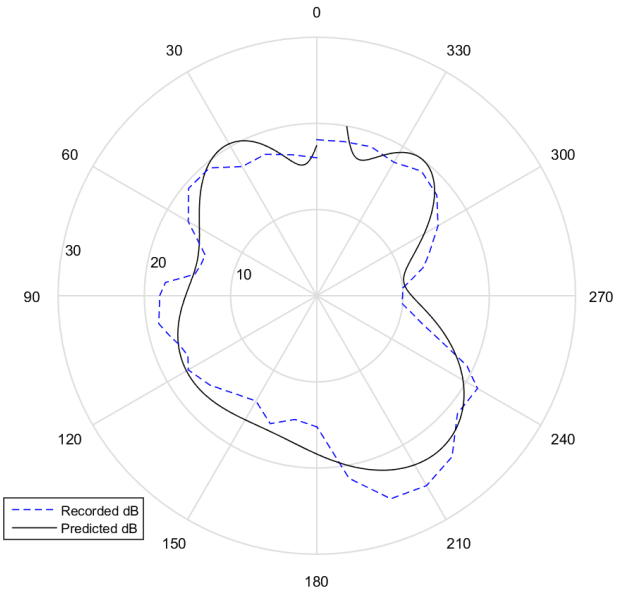


Figure 79. Comparison of Predicted and Recorded Noise Levels for Frequency = 157.4901 Hz, Wind Speed = 13.27 m/s

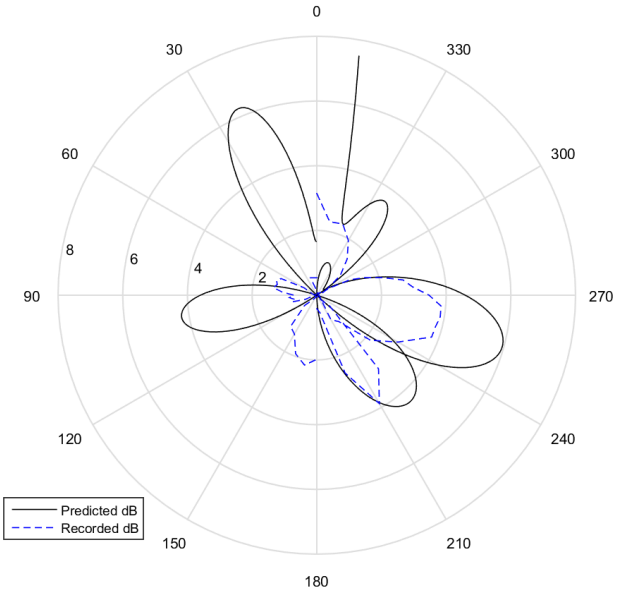


Figure 80. Comparison of Predicted and Recorded Noise Levels for Frequency = 198.4251 Hz, Wind Speed = 2.47 m/s

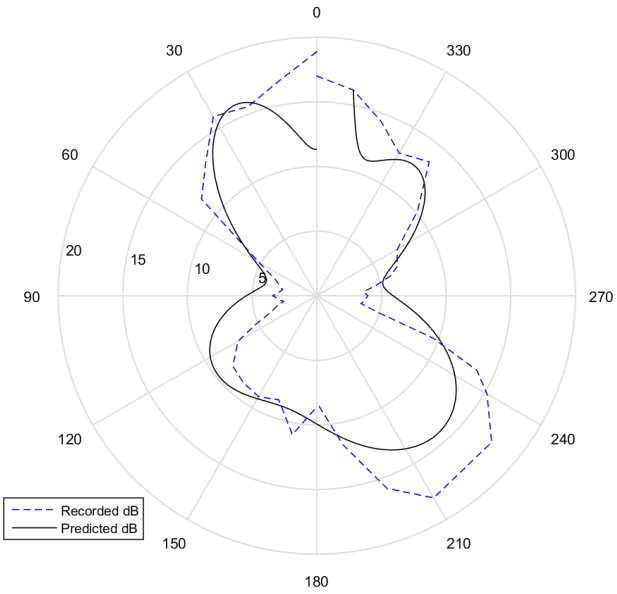


Figure 81. Comparison of Predicted and Recorded Noise Levels for Frequency = 198.4251 Hz, Wind Speed = 5.05 m/s

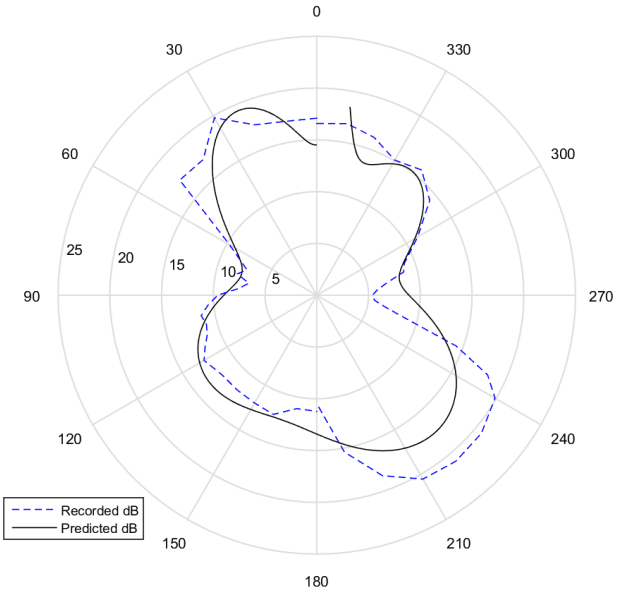


Figure 82. Comparison of Predicted and Recorded Noise Levels for Frequency = 198.4251 Hz, Wind Speed = 7.55 m/s

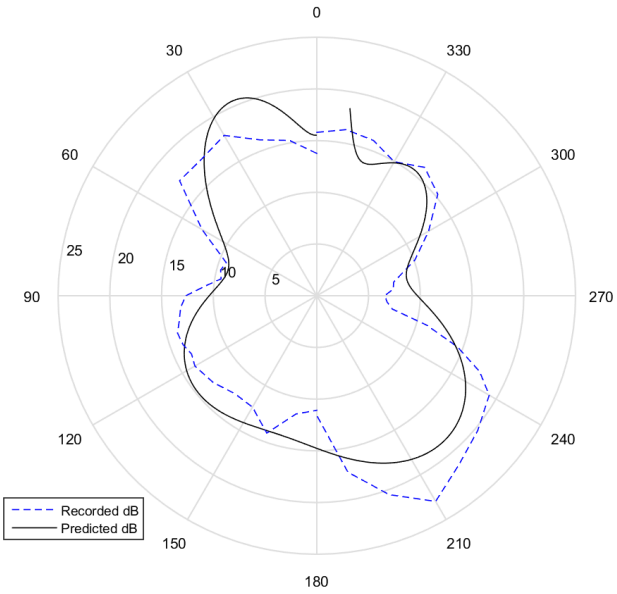


Figure 83. Comparison of Predicted and Recorded Noise Levels for Frequency = 198.4251 Hz, Wind Speed = 10.43 m/s

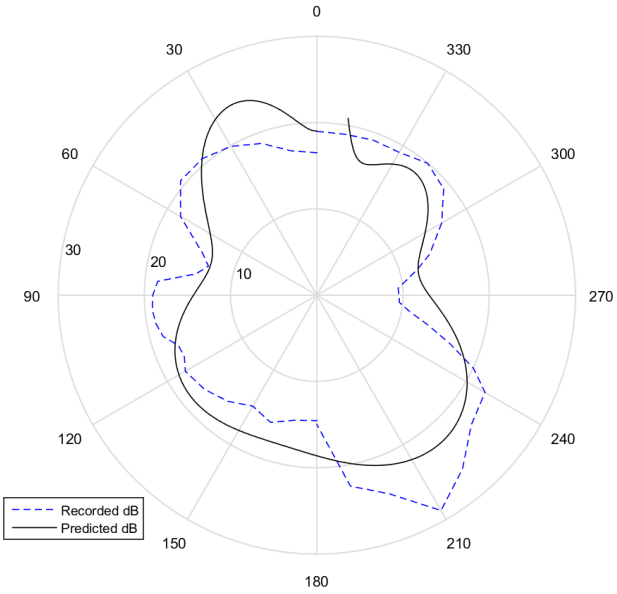


Figure 84. Comparison of Predicted and Recorded Noise Levels for Frequency = 198.4251 Hz, Wind Speed = 13.27 m/s

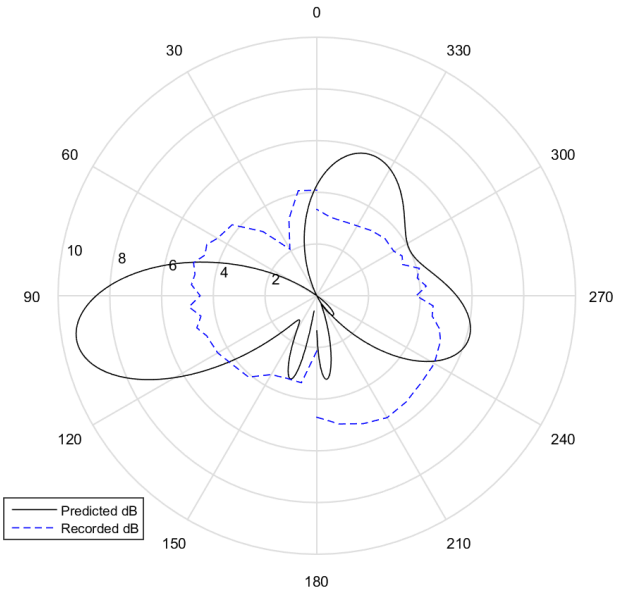


Figure 85. Comparison of Predicted and Recorded Noise Levels for Frequency = 250 Hz, Wind Speed = 2.47 m/s

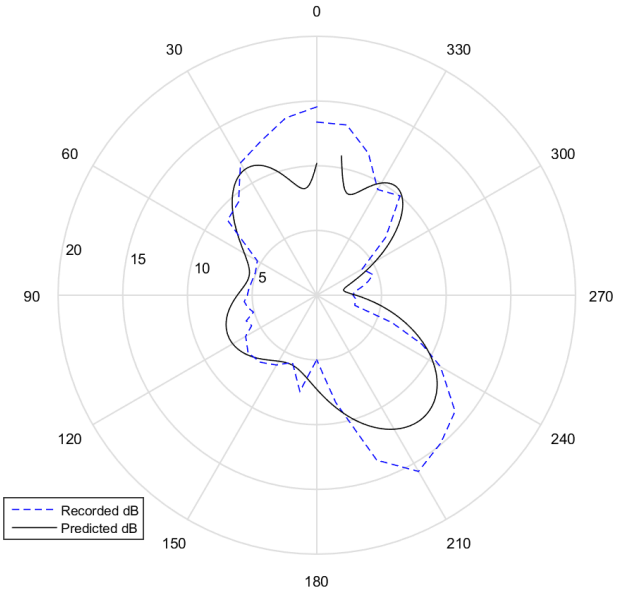


Figure 86. Comparison of Predicted and Recorded Noise Levels for Frequency = 250 Hz, Wind Speed = 5.05 m/s

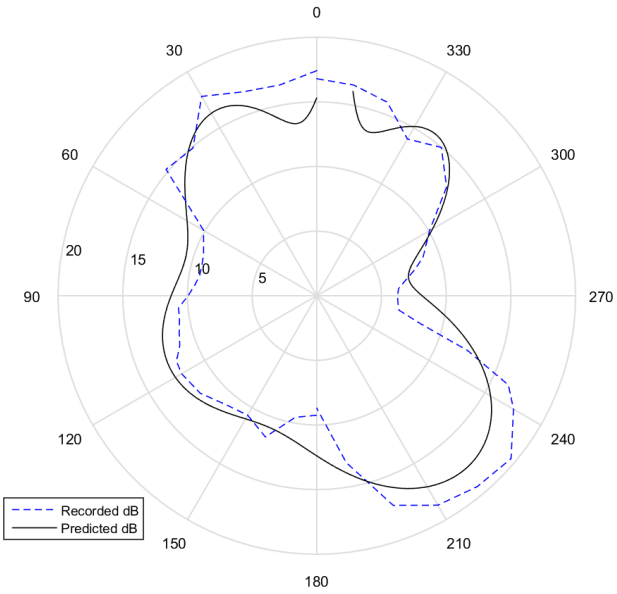


Figure 87. Comparison of Predicted and Recorded Noise Levels for Frequency = 250 Hz, Wind Speed = 7.55 m/s

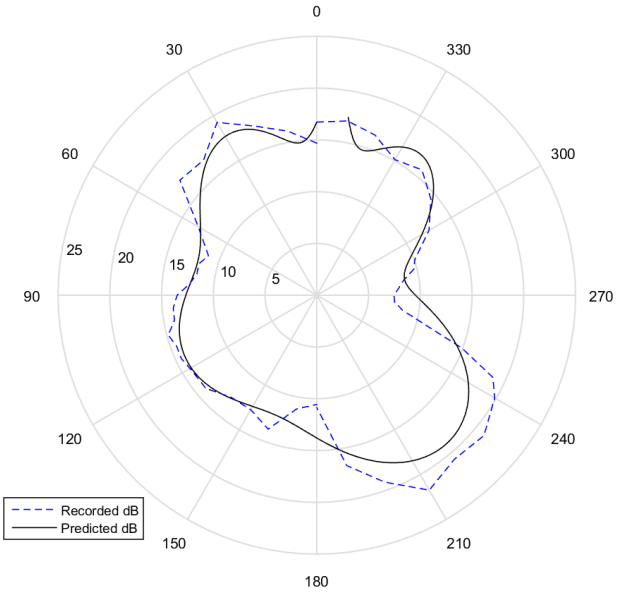


Figure 88. Comparison of Predicted and Recorded Noise Levels for Frequency = 250 Hz, Wind Speed = 10.43 m/s

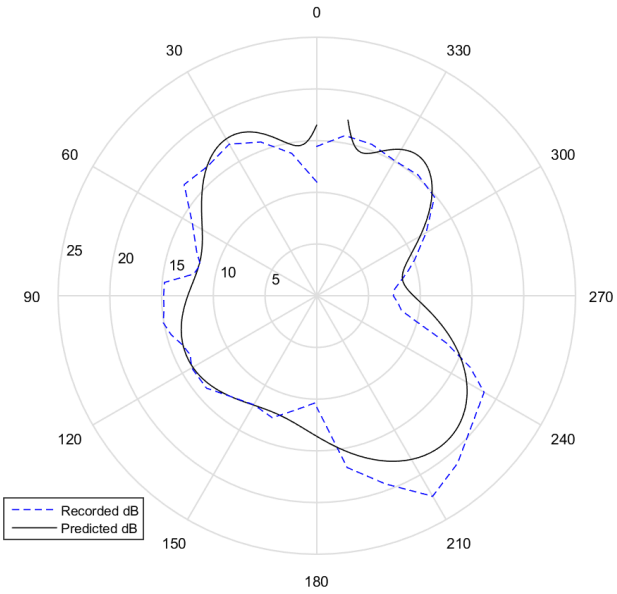


Figure 89. Comparison of Predicted and Recorded Noise Levels for Frequency = 250 Hz, Wind Speed = 13.27 m/s

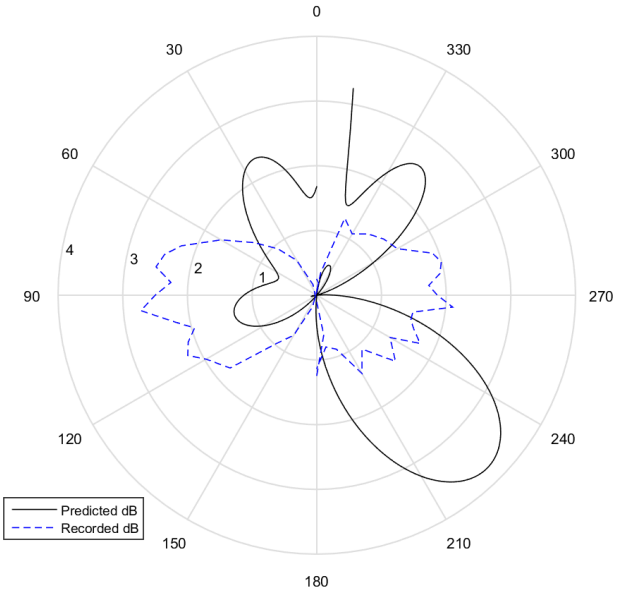


Figure 90. Comparison of Predicted and Recorded Noise Levels for Frequency = 314.9803 Hz, Wind Speed = 2.47 m/s

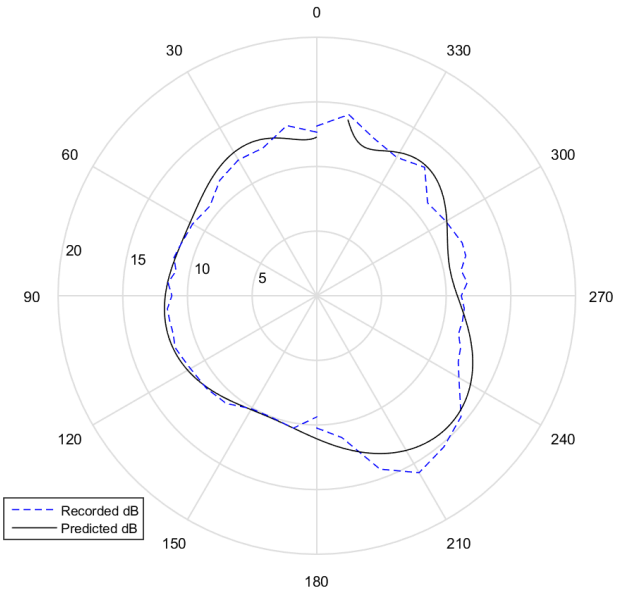


Figure 91. Comparison of Predicted and Recorded Noise Levels for Frequency = 314.9803 Hz, Wind Speed = 5.05 m/s

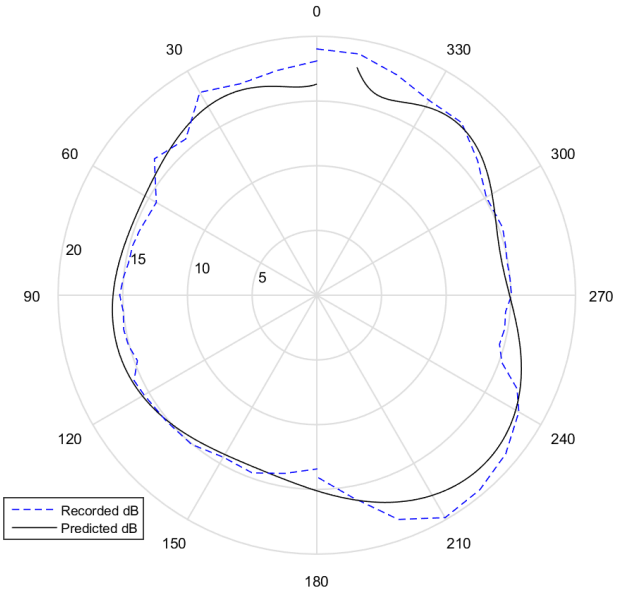


Figure 92. Comparison of Predicted and Recorded Noise Levels for Frequency = 314.9803 Hz, Wind Speed = 7.55 m/s

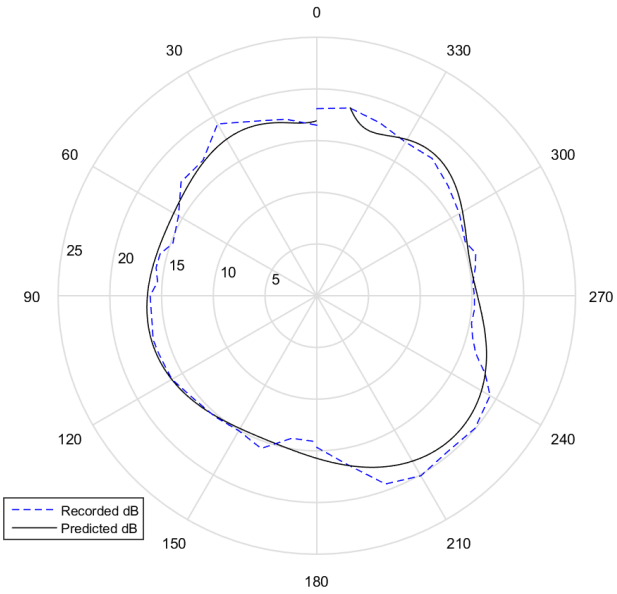


Figure 93. Comparison of Predicted and Recorded Noise Levels for Frequency = 314.9803 Hz, Wind Speed = 10.43 m/s

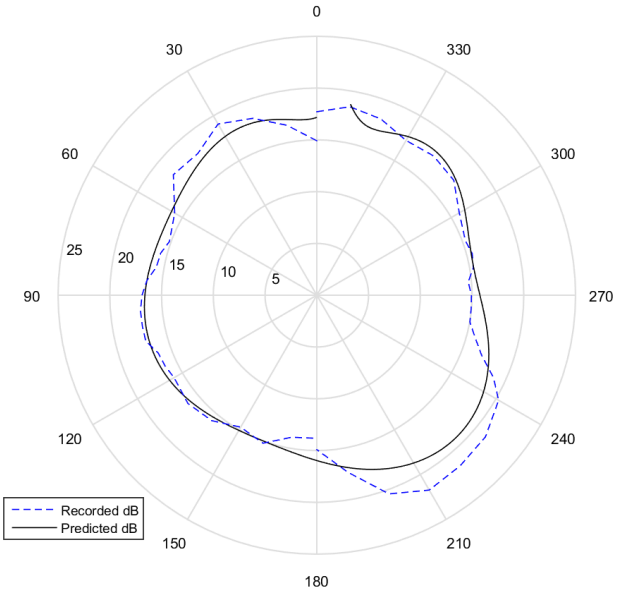


Figure 94. Comparison of Predicted and Recorded Noise Levels for Frequency = 314.9803 Hz, Wind Speed = 13.27 m/s

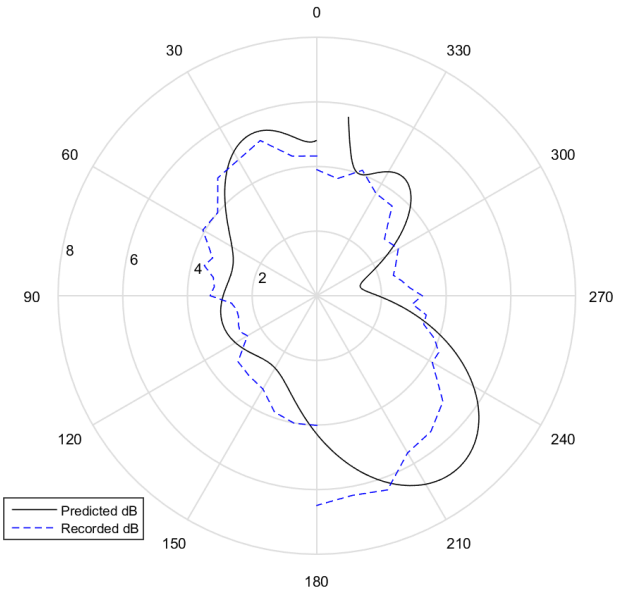


Figure 95. Comparison of Predicted and Recorded Noise Levels for Frequency = 396.8503 Hz, Wind Speed = 2.47 m/s

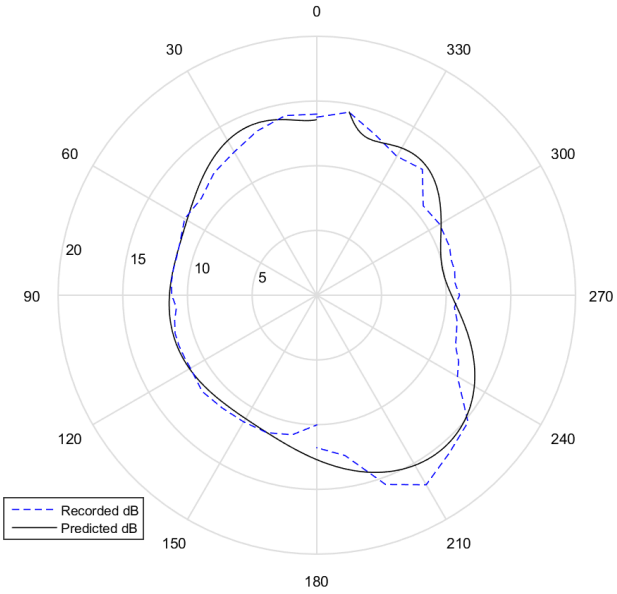


Figure 96. Comparison of Predicted and Recorded Noise Levels for Frequency = 396.8503 Hz, Wind Speed = 5.05 m/s

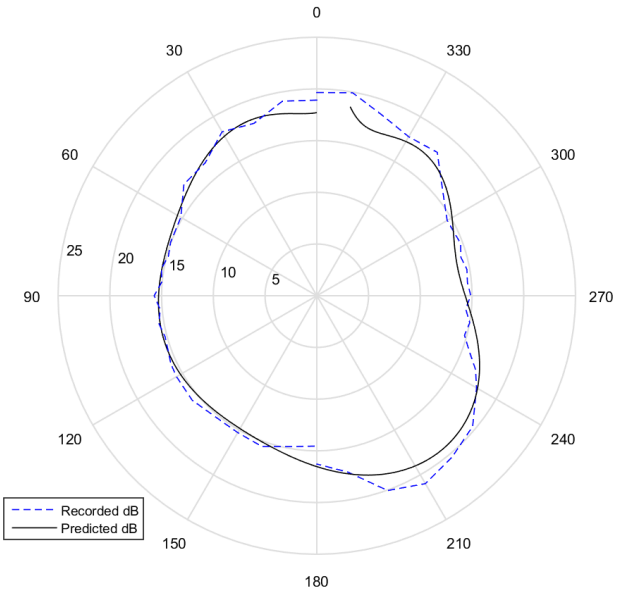


Figure 97. Comparison of Predicted and Recorded Noise Levels for Frequency = 396.8503 Hz, Wind Speed = 7.55 m/s

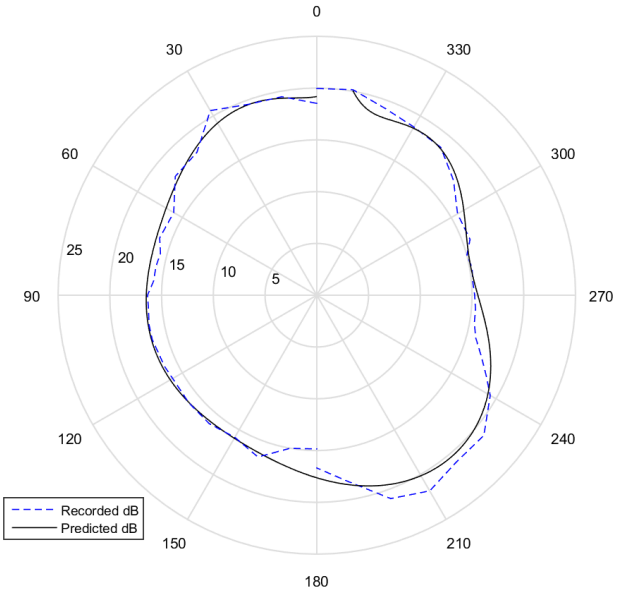


Figure 98. Comparison of Predicted and Recorded Noise Levels for Frequency = 396.8503 Hz, Wind Speed = 10.43 m/s

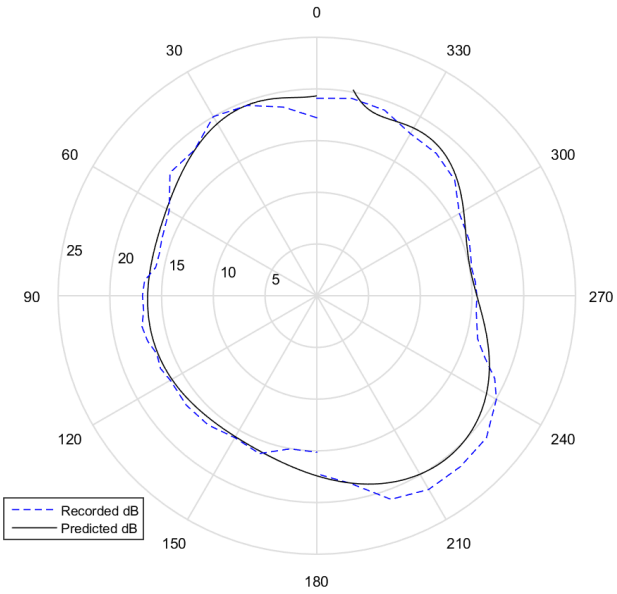


Figure 99. Comparison of Predicted and Recorded Noise Levels for Frequency = 396.8503 Hz, Wind Speed = 13.27 m/s

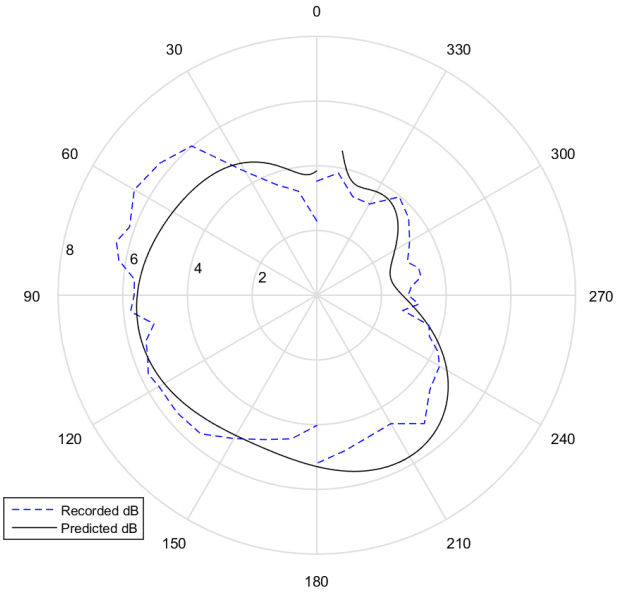


Figure 100. Comparison of Predicted and Recorded Noise Levels for Frequency = 500 Hz, Wind Speed = 2.47 m/s

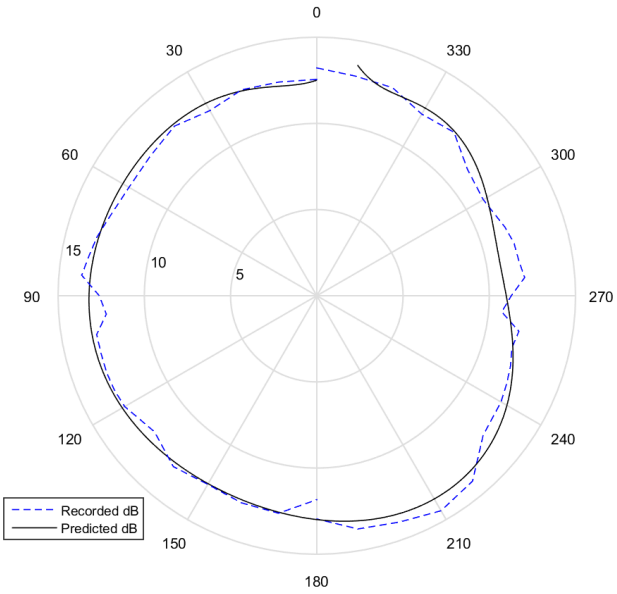


Figure 101. Comparison of Predicted and Recorded Noise Levels for Frequency = 500 Hz, Wind Speed = 5.05 m/s

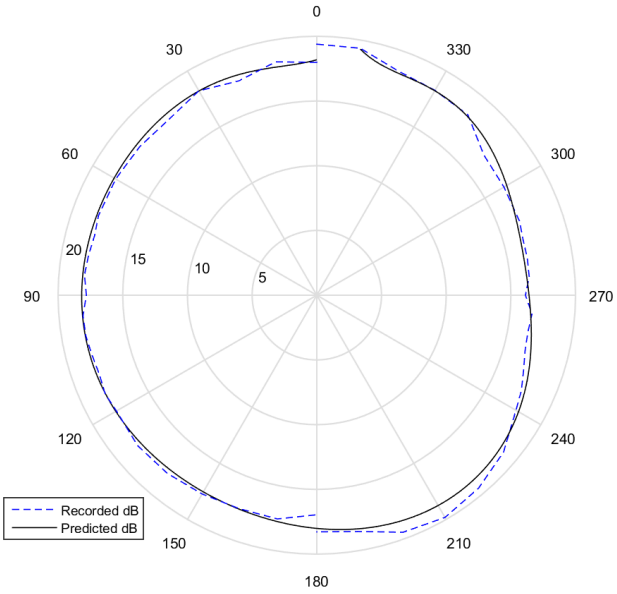


Figure 102. Comparison of Predicted and Recorded Noise Levels for Frequency = 500 Hz, Wind Speed = 7.55 m/s

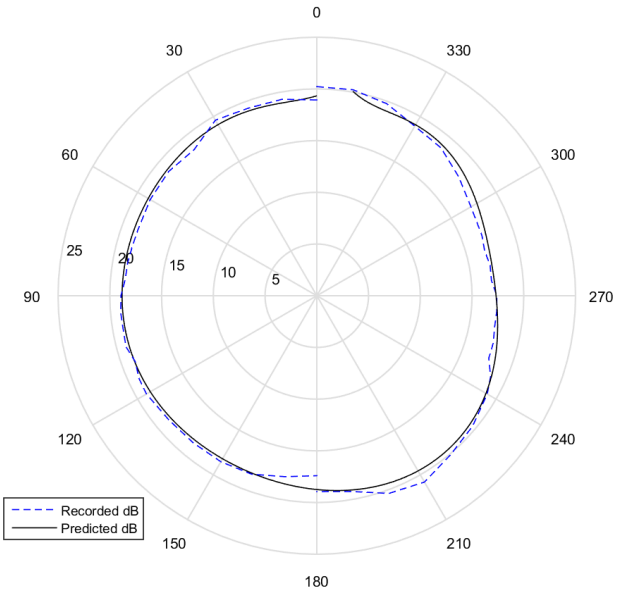


Figure 103. Comparison of Predicted and Recorded Noise Levels for Frequency = 500 Hz, Wind Speed = 10.43 m/s

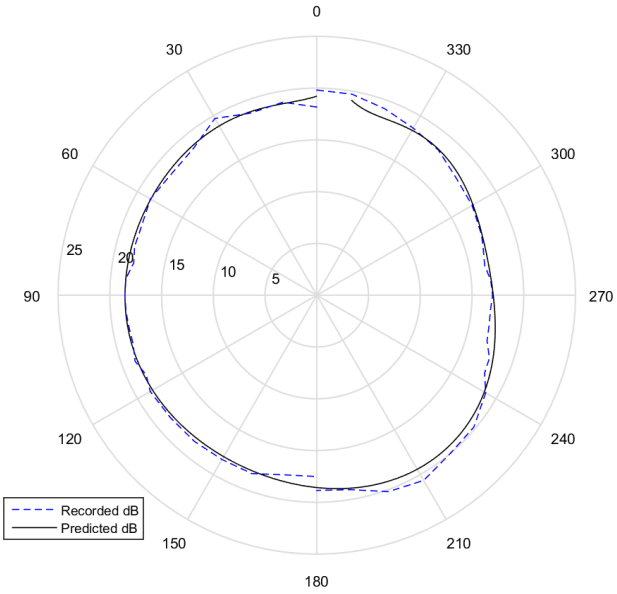


Figure 104. Comparison of Predicted and Recorded Noise Levels for Frequency = 500 Hz, Wind Speed = 13.27 m/s

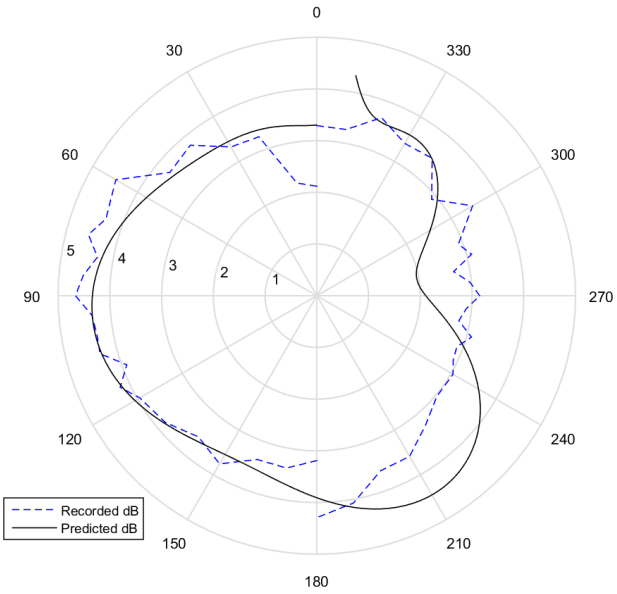


Figure 105. Comparison of Predicted and Recorded Noise Levels for Frequency = 629.9605 Hz, Wind Speed = 2.47 m/s

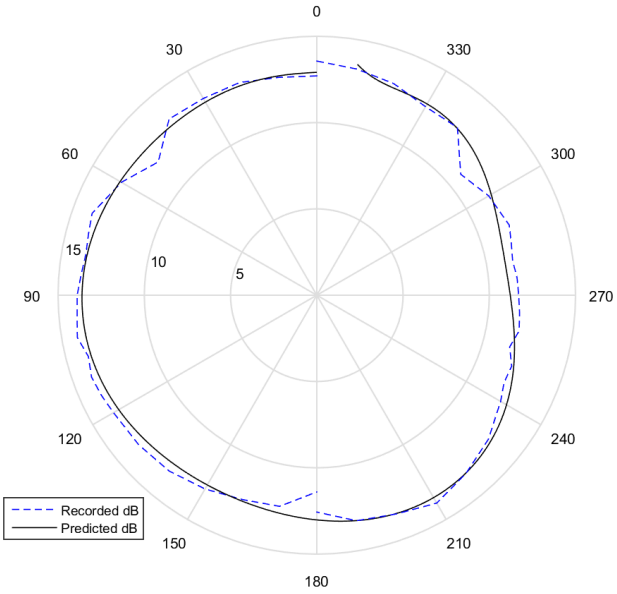


Figure 106. Comparison of Predicted and Recorded Noise Levels for Frequency = 629.9605 Hz, Wind Speed = 5.05 m/s

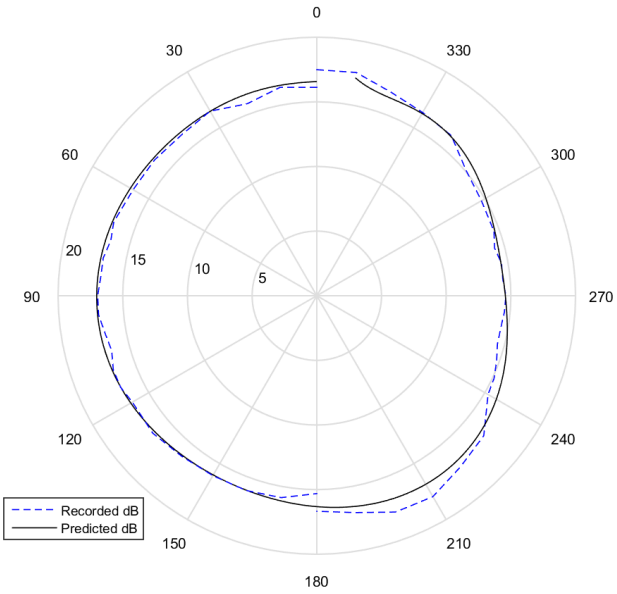


Figure 107. Comparison of Predicted and Recorded Noise Levels for Frequency = 629.9605 Hz, Wind Speed = 7.55 m/s

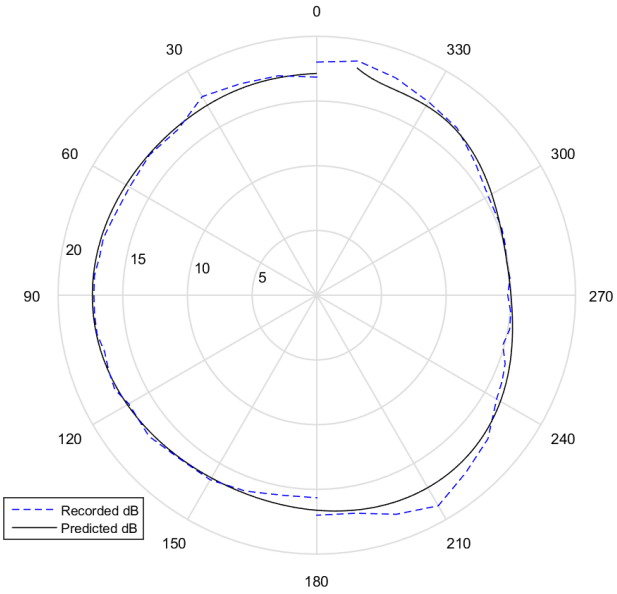


Figure 108. Comparison of Predicted and Recorded Noise Levels for Frequency = 629.9605 Hz, Wind Speed = 10.43 m/s

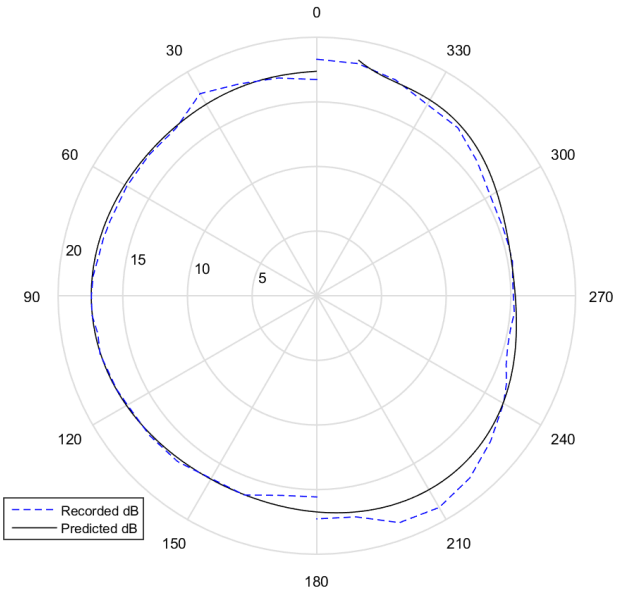


Figure 109. Comparison of Predicted and Recorded Noise Levels for Frequency = 629.9605 Hz, Wind Speed = 13.27 m/s

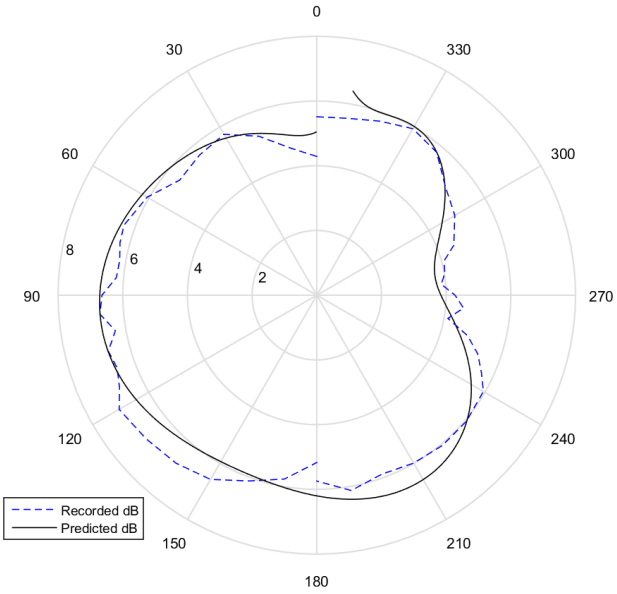


Figure 110. Comparison of Predicted and Recorded Noise Levels for Frequency = 793.7005 Hz, Wind Speed = 2.47 m/s

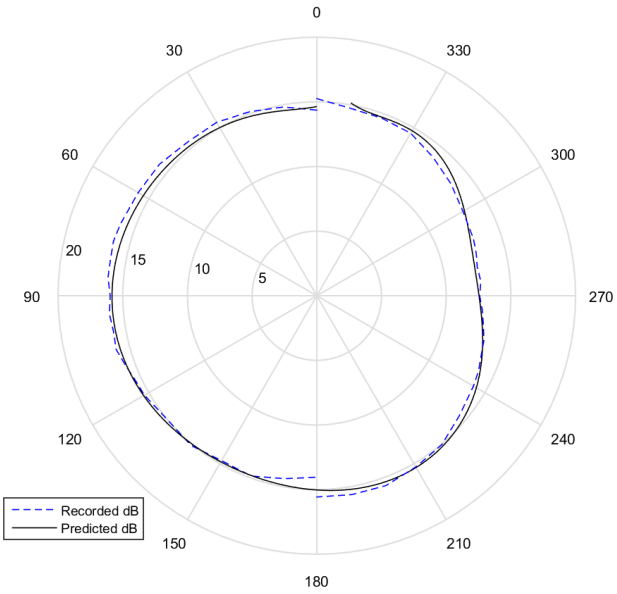


Figure 111. Comparison of Predicted and Recorded Noise Levels for Frequency = 793.7005 Hz, Wind Speed = 5.05 m/s

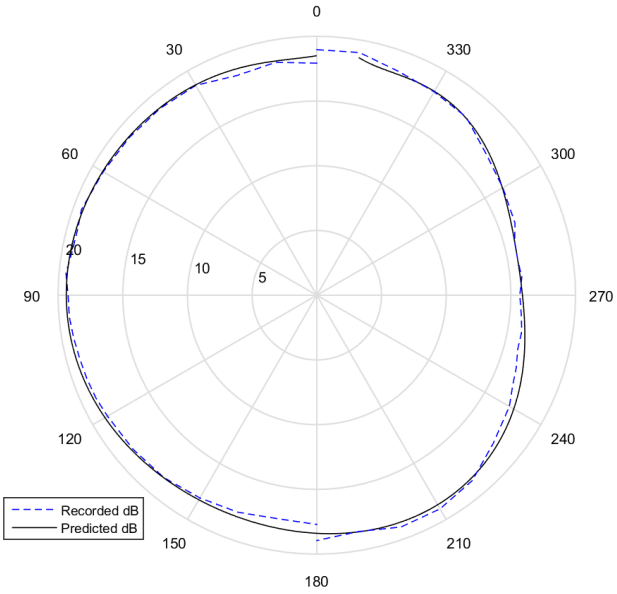


Figure 112. Comparison of Predicted and Recorded Noise Levels for Frequency = 793.7005 Hz, Wind Speed = 7.55 m/s

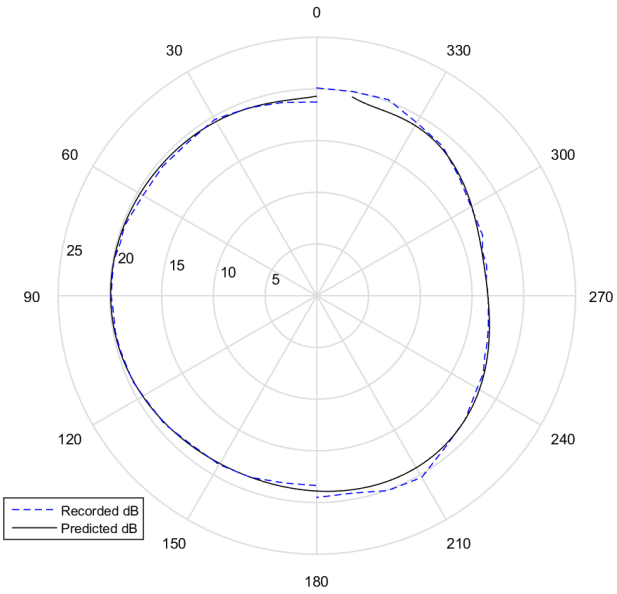


Figure 113. Comparison of Predicted and Recorded Noise Levels for Frequency = 793.7005 Hz, Wind Speed = 10.43 m/s

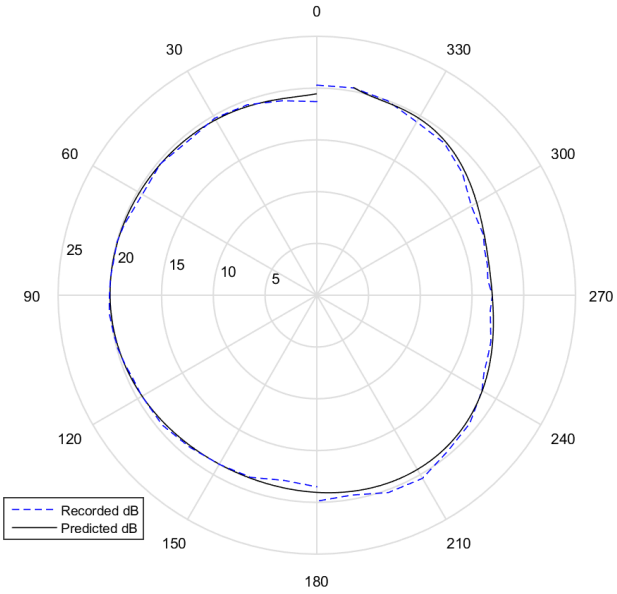


Figure 114. Comparison of Predicted and Recorded Noise Levels for Frequency = 793.7005 Hz, Wind Speed = 13.27 m/s

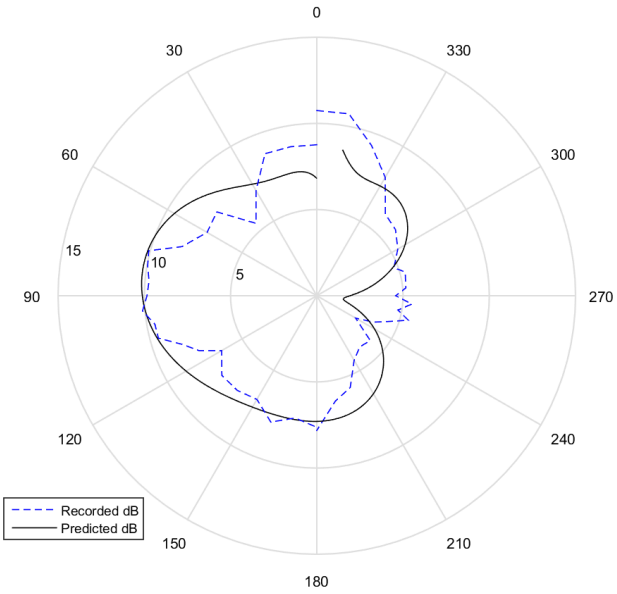


Figure 115. Comparison of Predicted and Recorded Noise Levels for Frequency = 1,000 Hz, Wind Speed = 2.47 m/s

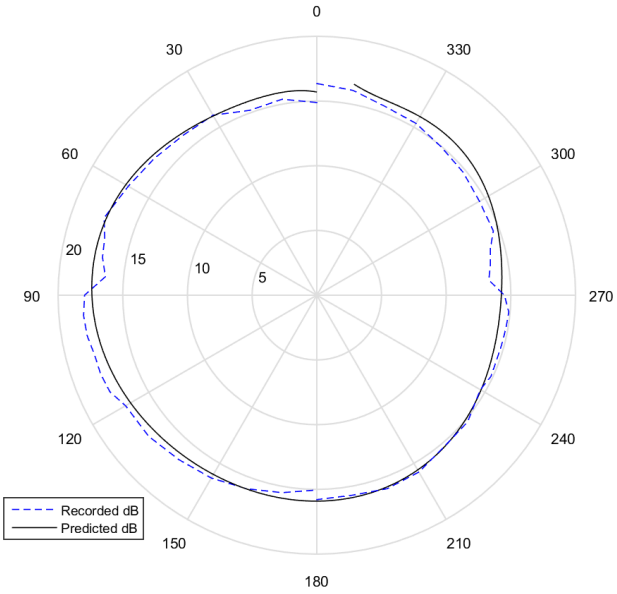


Figure 116. Comparison of Predicted and Recorded Noise Levels for Frequency = 1,000 Hz, Wind Speed = 5.05 m/s

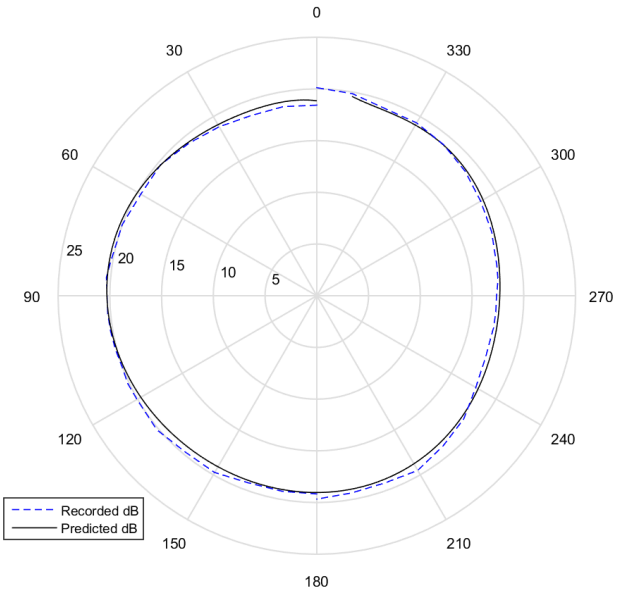


Figure 117. Comparison of Predicted and Recorded Noise Levels for Frequency = 1,000 Hz, Wind Speed = 7.55 m/s

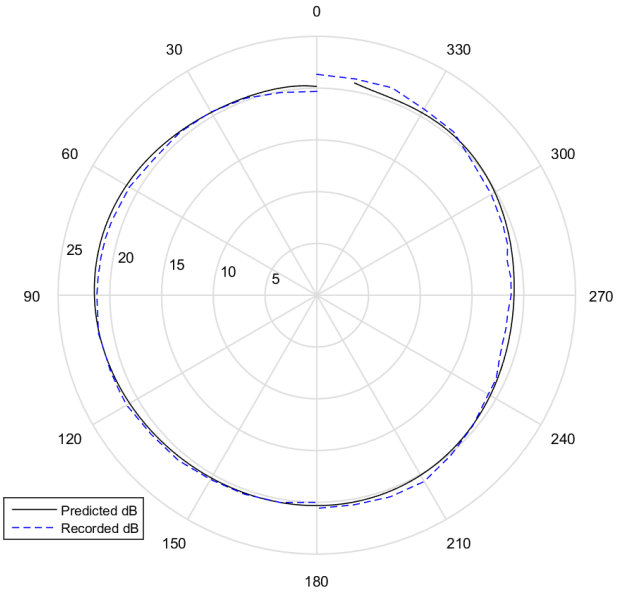


Figure 118. Comparison of Predicted and Recorded Noise Levels for Frequency = 1,000 Hz, Wind Speed = 10.43 m/s

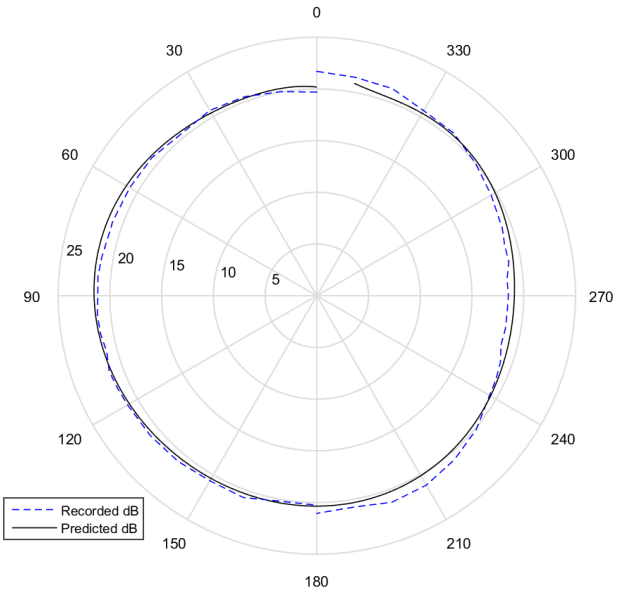


Figure 119. Comparison of Predicted and Recorded Noise Levels for Frequency = 1,000 Hz, Wind Speed = 13.27 m/s

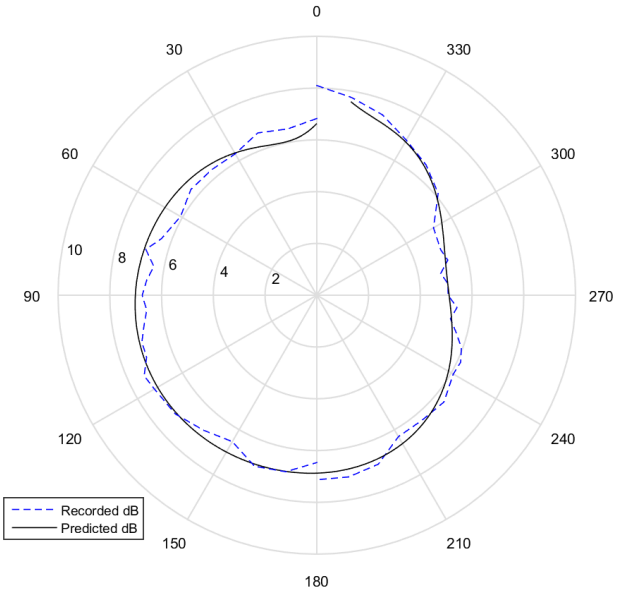


Figure 120. Comparison of Predicted and Recorded Noise Levels for Frequency = 1,259.9211 Hz, Wind Speed = 2.47 m/s

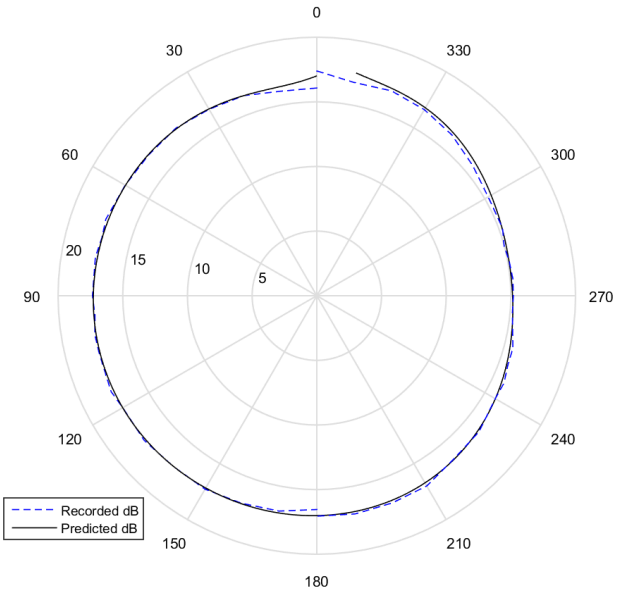


Figure 121. Comparison of Predicted and Recorded Noise Levels for Frequency = 1,259.9211 Hz, Wind Speed = 5.05 m/s

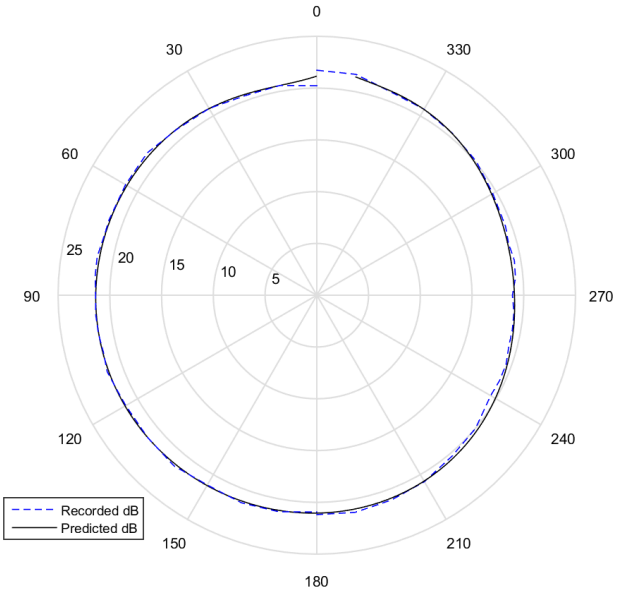


Figure 122. Comparison of Predicted and Recorded Noise Levels for Frequency = 1,259.9211 Hz, Wind Speed = 7.55 m/s

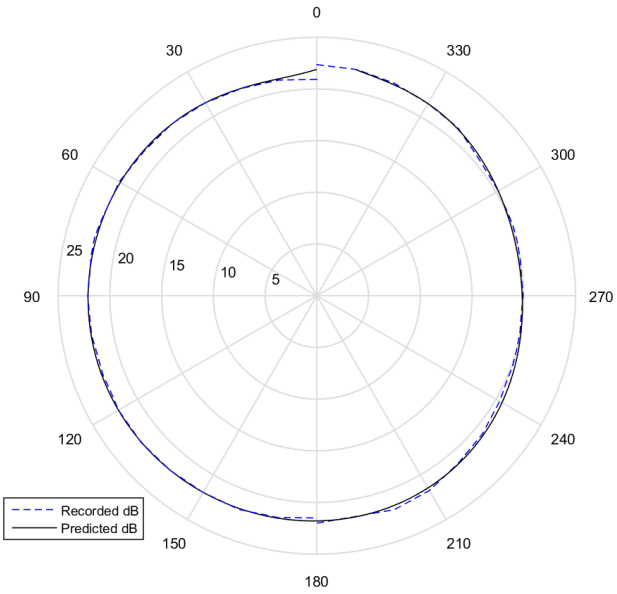


Figure 123. Comparison of Predicted and Recorded Noise Levels for Frequency = 1,259.9211 Hz, Wind Speed = 10.43 m/s

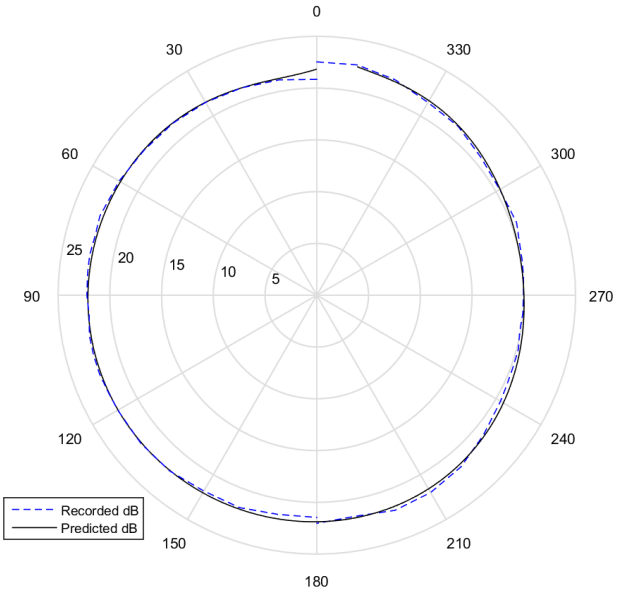


Figure 124. Comparison of Predicted and Recorded Noise Levels for Frequency = 1,259.9211 Hz, Wind Speed = 13.27 m/s

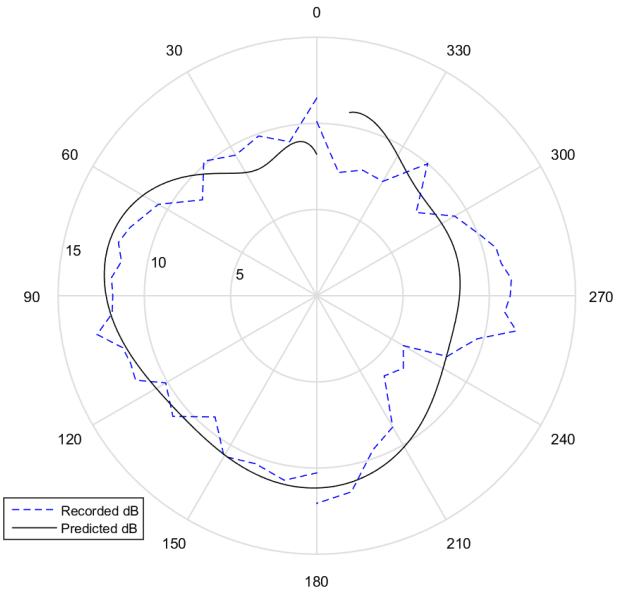


Figure 125. Comparison of Predicted and Recorded Noise Levels for Frequency = 1,587.4011 Hz, Wind Speed = 2.47 m/s

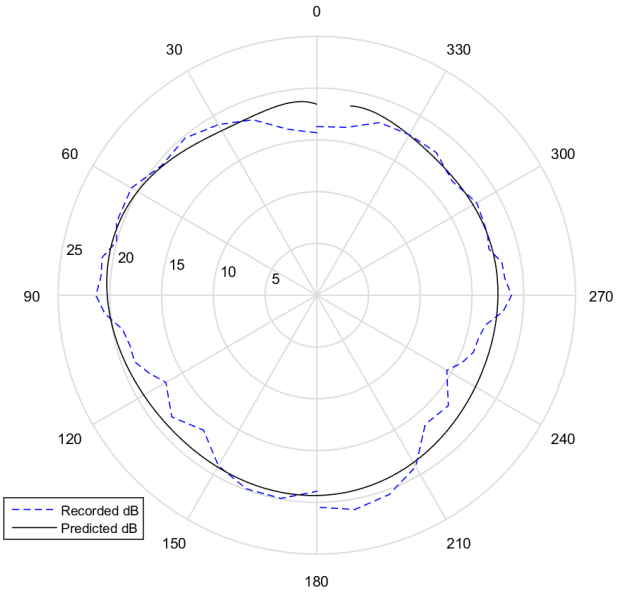


Figure 126. Comparison of Predicted and Recorded Noise Levels for Frequency = 1,587.4011 Hz, Wind Speed = 5.05 m/s

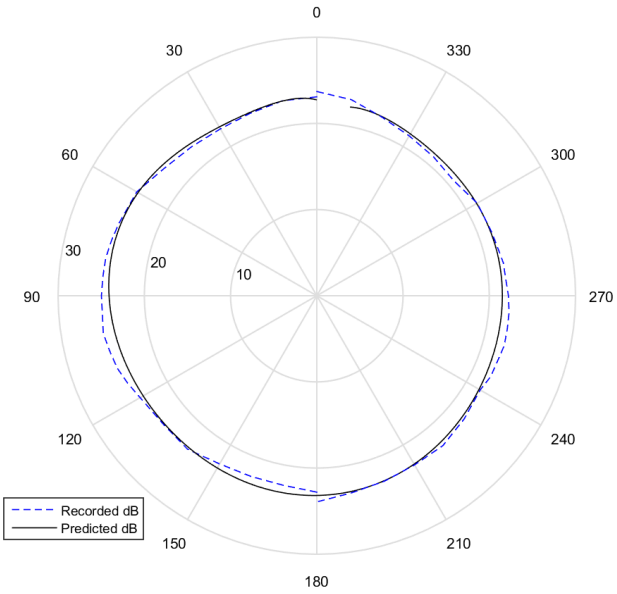


Figure 127. Comparison of Predicted and Recorded Noise Levels for Frequency = 1,587.4011 Hz, Wind Speed = 7.55 m/s

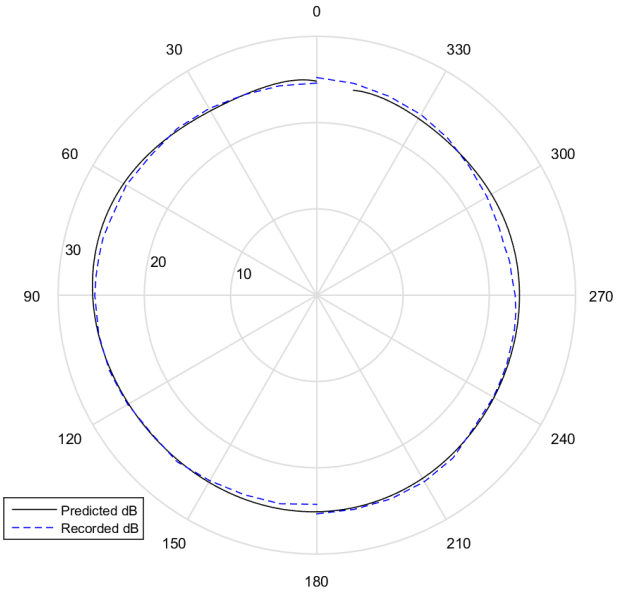


Figure 128. Comparison of Predicted and Recorded Noise Levels for Frequency = 1,587.4011 Hz, Wind Speed = 10.43 m/s

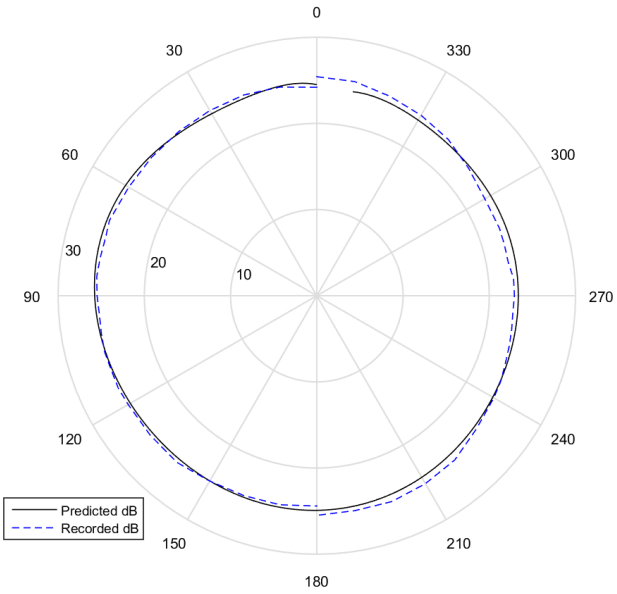


Figure 129. Comparison of Predicted and Recorded Noise Levels for Frequency = 1,587.4011 Hz, Wind Speed = 13.27 m/s

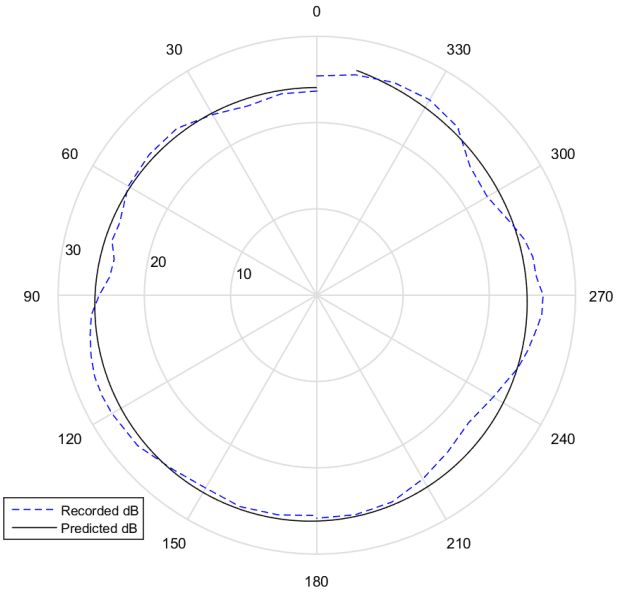


Figure 130. Comparison of Predicted and Recorded Noise Levels for Frequency = 2,000 Hz, Wind Speed = 2.47 m/s

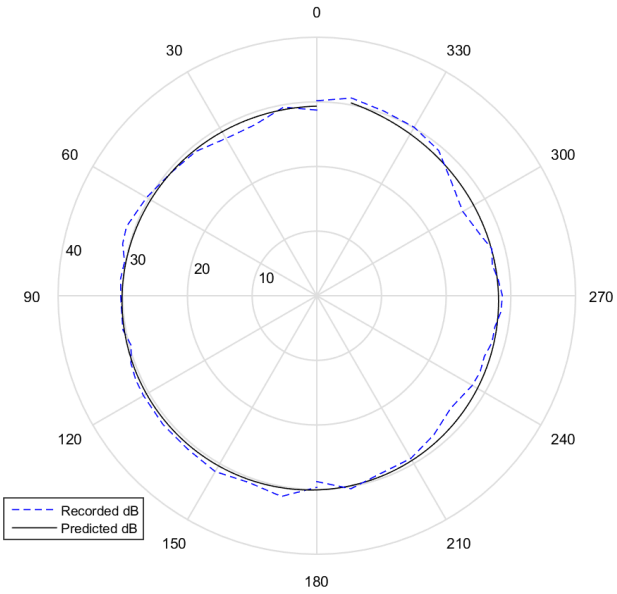


Figure 131. Comparison of Predicted and Recorded Noise Levels for Frequency = 2,000 Hz, Wind Speed = 5.05 m/s

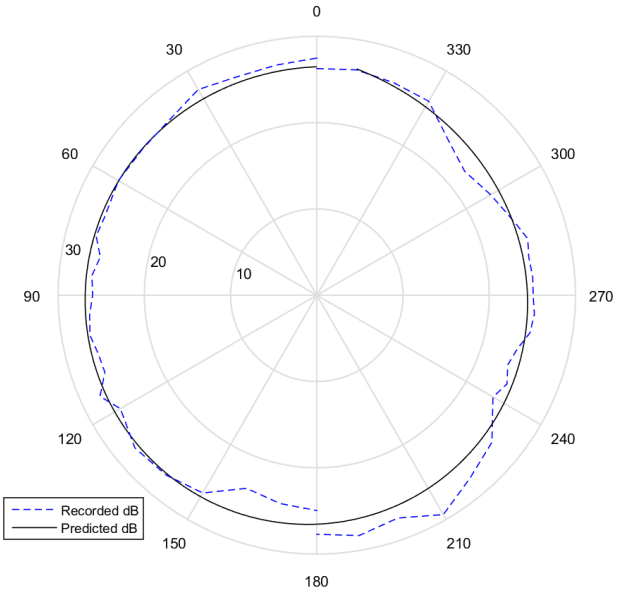


Figure 132. Comparison of Predicted and Recorded Noise Levels for Frequency = 2,000 Hz, Wind Speed = 7.55 m/s

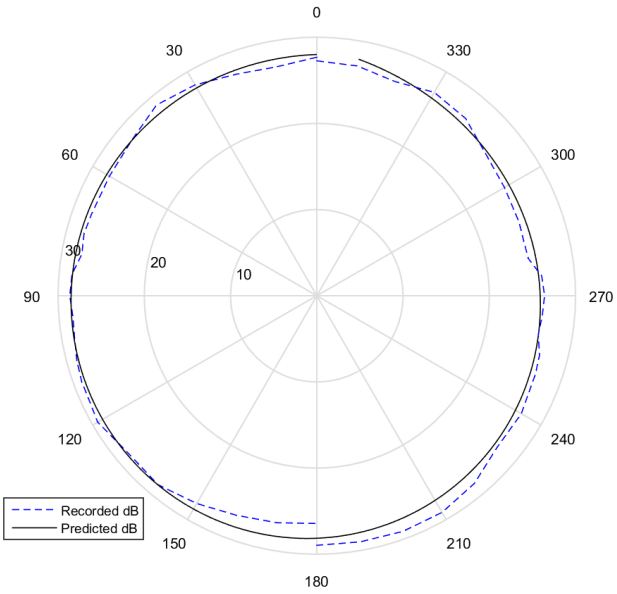


Figure 133. Comparison of Predicted and Recorded Noise Levels for Frequency = 2,000 Hz, Wind Speed = 10.43 m/s

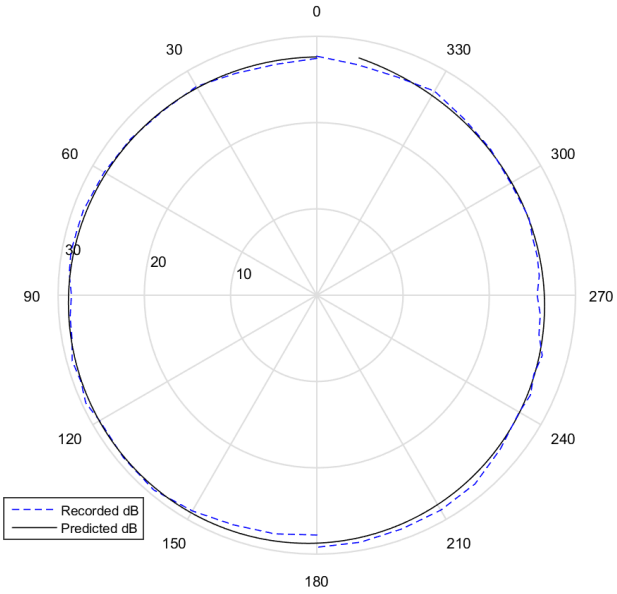


Figure 134. Comparison of Predicted and Recorded Noise Levels for Frequency = 2,000 Hz, Wind Speed = 13.27 m/s

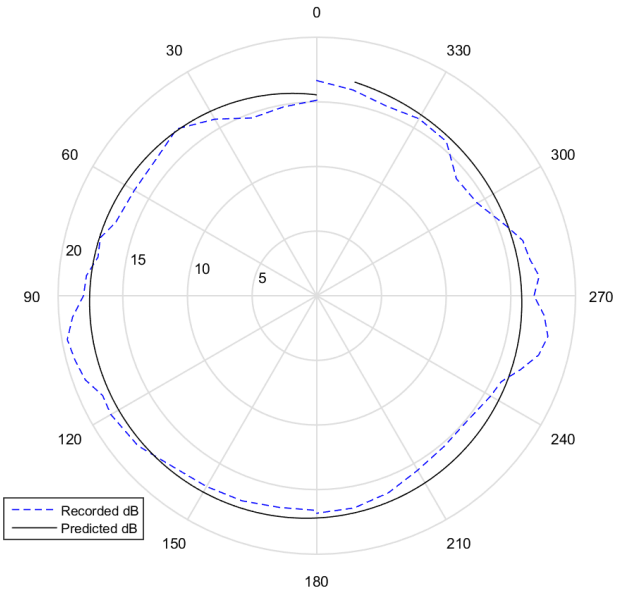


Figure 135. Comparison of Predicted and Recorded Noise Levels for Frequency = 2,519.8421 Hz, Wind Speed = 2.47 m/s

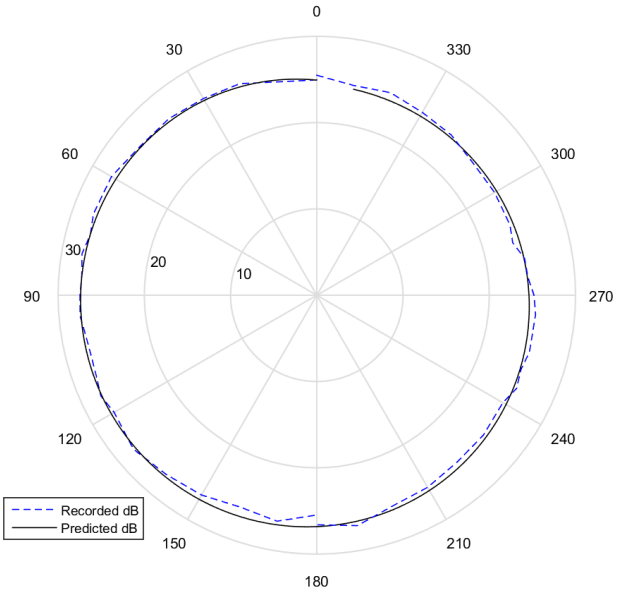


Figure 136. Comparison of Predicted and Recorded Noise Levels for Frequency = 2,519.8421 Hz, Wind Speed = 5.05 m/s

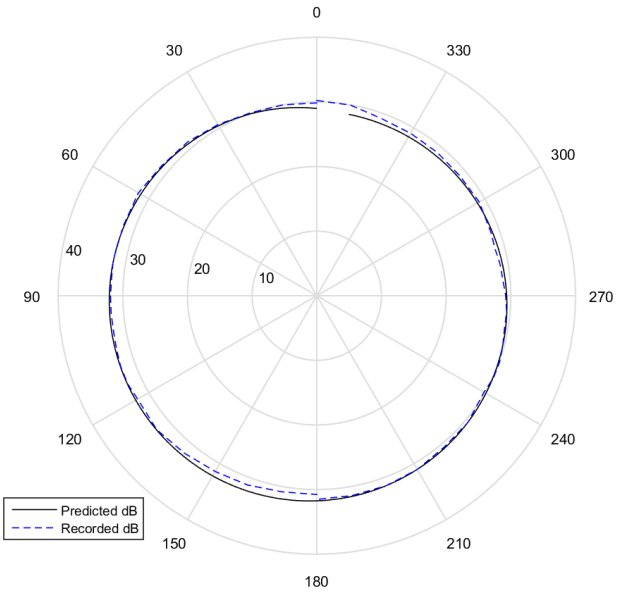


Figure 137. Comparison of Predicted and Recorded Noise Levels for Frequency = 2,519.8421 Hz, Wind Speed = 7.55 m/s

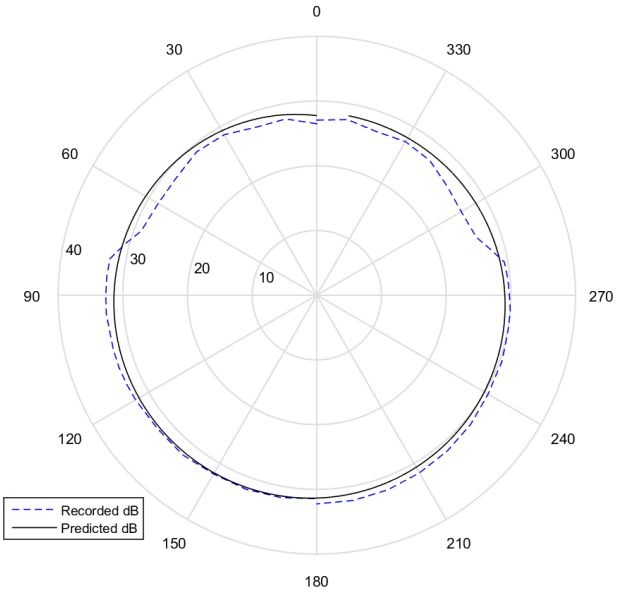


Figure 138. Comparison of Predicted and Recorded Noise Levels for Frequency = 2,519.8421 Hz, Wind Speed = 10.43 m/s

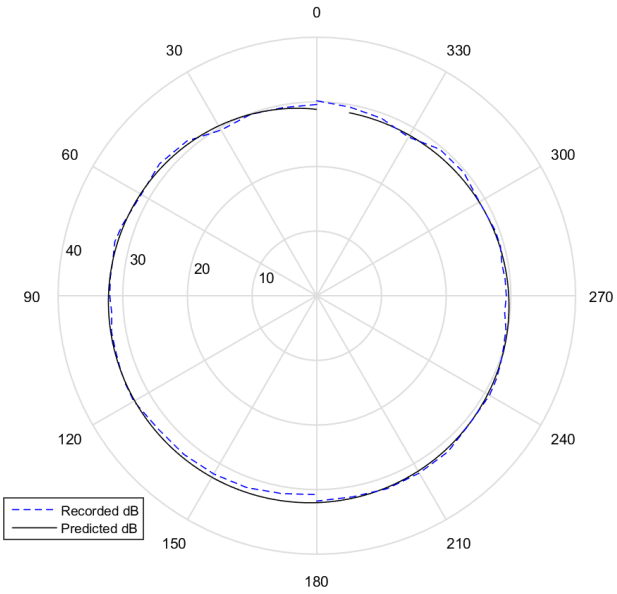


Figure 139. Comparison of Predicted and Recorded Noise Levels for Frequency = 2,519.8421 Hz, Wind Speed = 13.27 m/s

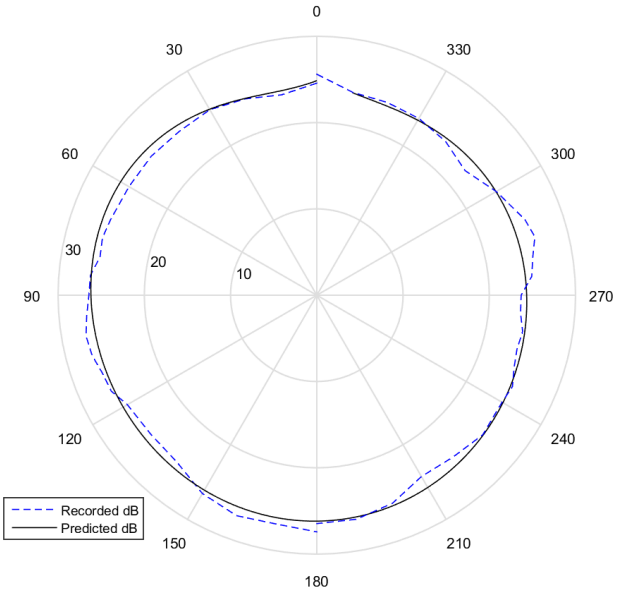


Figure 140. Comparison of Predicted and Recorded Noise Levels for Frequency = 3,174.8021 Hz, Wind Speed = 2.47 m/s

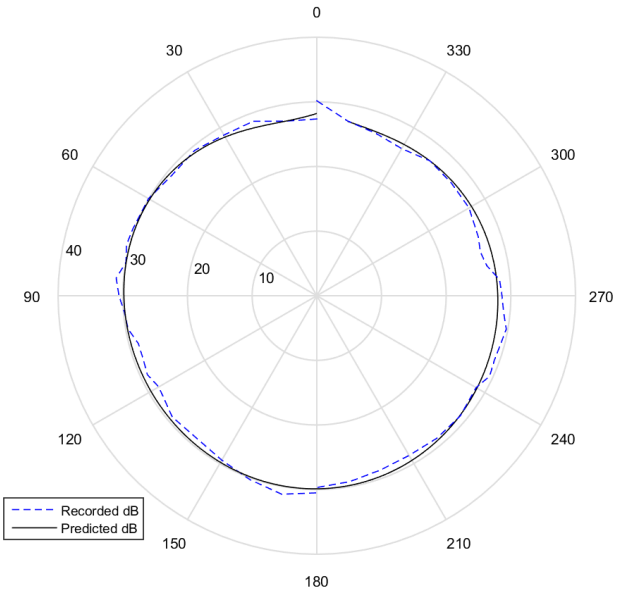


Figure 141. Comparison of Predicted and Recorded Noise Levels for Frequency = 3,174.8021 Hz, Wind Speed = 5.05 m/s

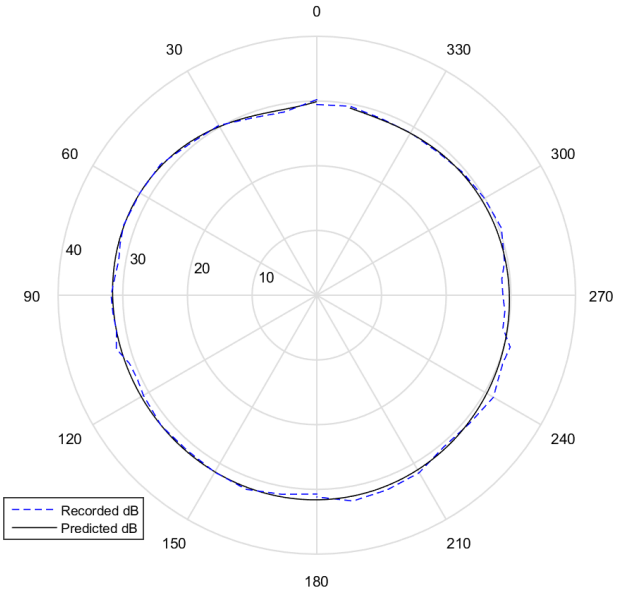


Figure 142. Comparison of Predicted and Recorded Noise Levels for Frequency = 3,174.8021 Hz, Wind Speed = 7.55 m/s

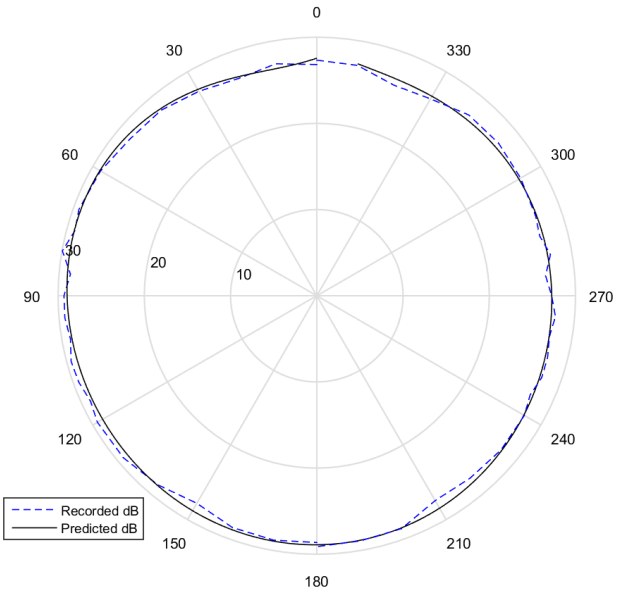


Figure 143. Comparison of Predicted and Recorded Noise Levels for Frequency = 3,174.8021 Hz, Wind Speed = 10.43 m/s

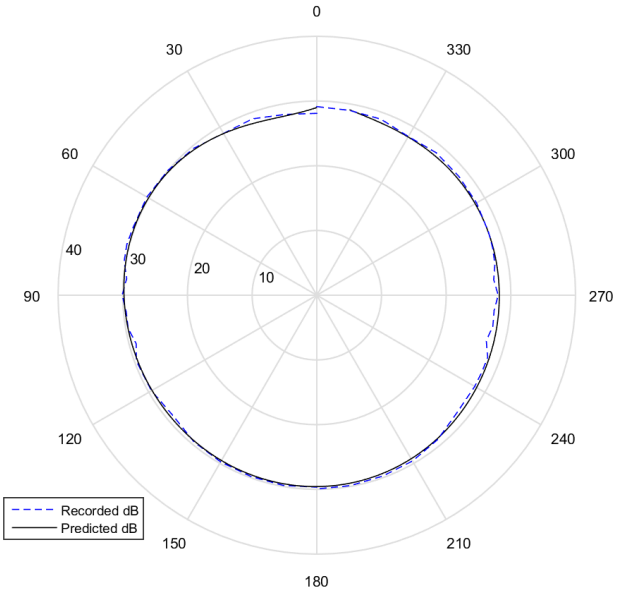


Figure 144. Comparison of Predicted and Recorded Noise Levels for Frequency = 3,174.8021 Hz, Wind Speed = 13.27 m/s

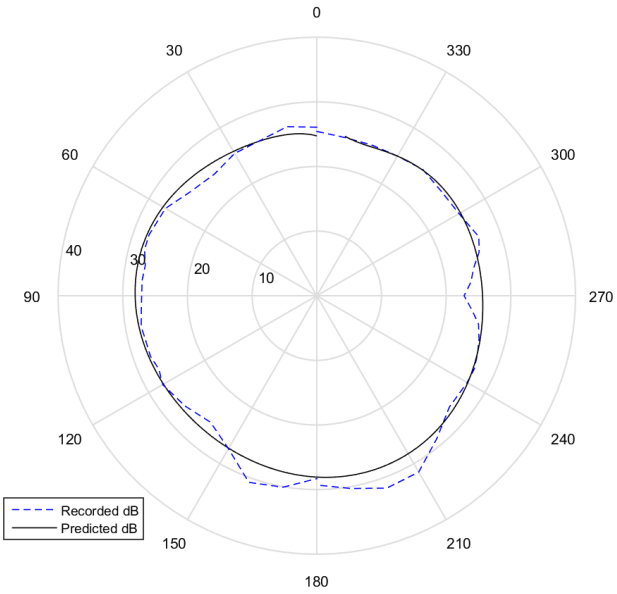


Figure 145. Comparison of Predicted and Recorded Noise Levels for Frequency = 4,000 Hz, Wind Speed = 2.47 m/s

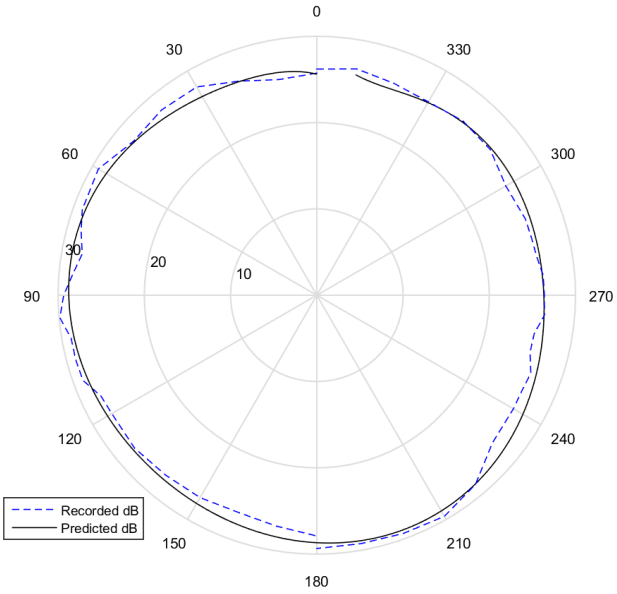


Figure 146. Comparison of Predicted and Recorded Noise Levels for Frequency = 4,000 Hz, Wind Speed = 5.05 m/s

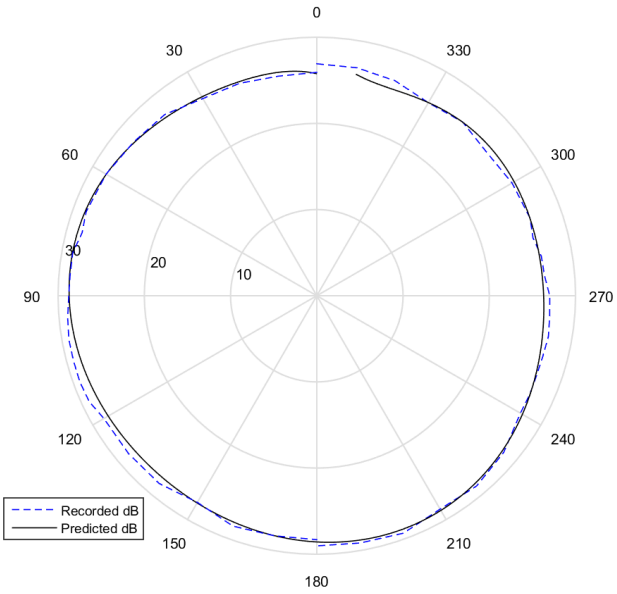


Figure 147. Comparison of Predicted and Recorded Noise Levels for Frequency = 4,000 Hz, Wind Speed = 7.55 m/s

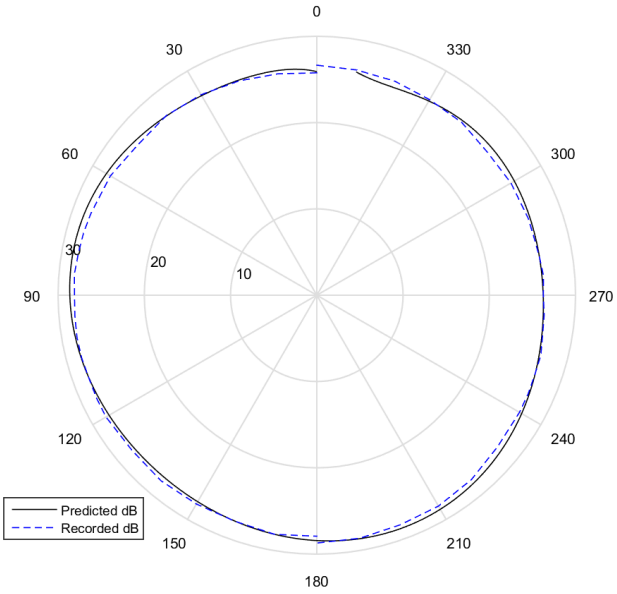


Figure 148. Comparison of Predicted and Recorded Noise Levels for Frequency = 4,000 Hz, Wind Speed = 10.43 m/s

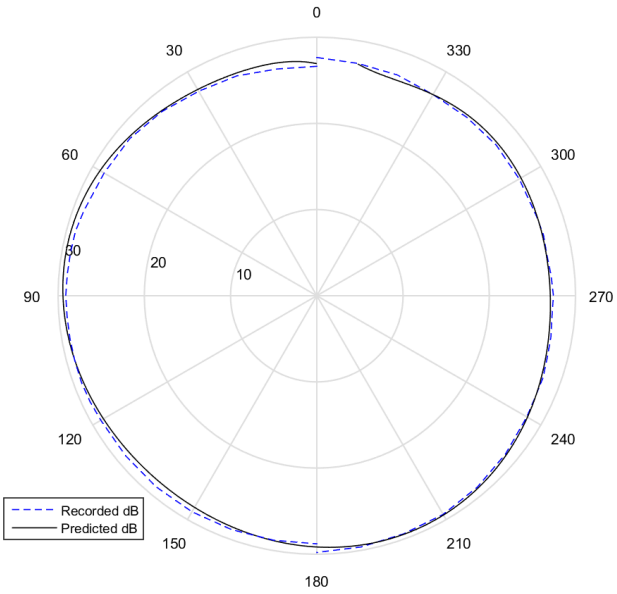


Figure 149. Comparison of Predicted and Recorded Noise Levels for Frequency = 4,000 Hz, Wind Speed = 13.27 m/s

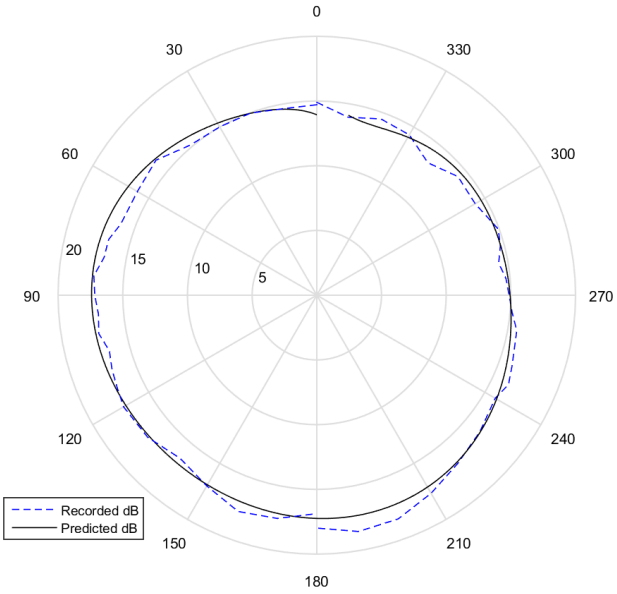


Figure 150. Comparison of Predicted and Recorded Noise Levels for Frequency = 5,039.6842 Hz, Wind Speed = 2.47 m/s

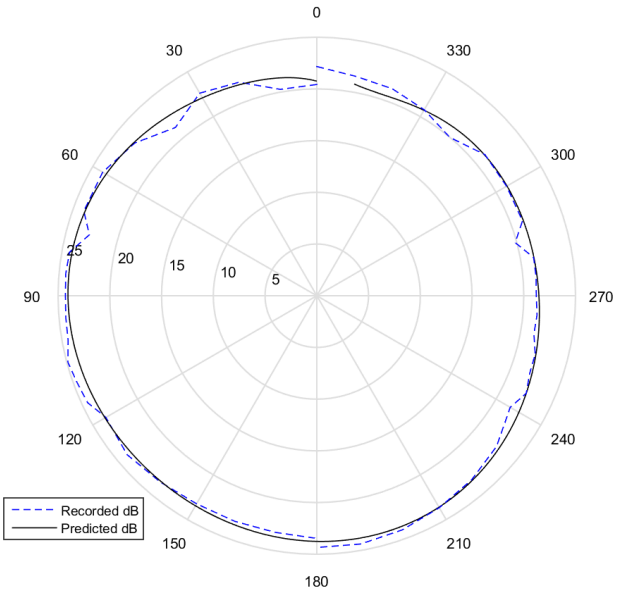
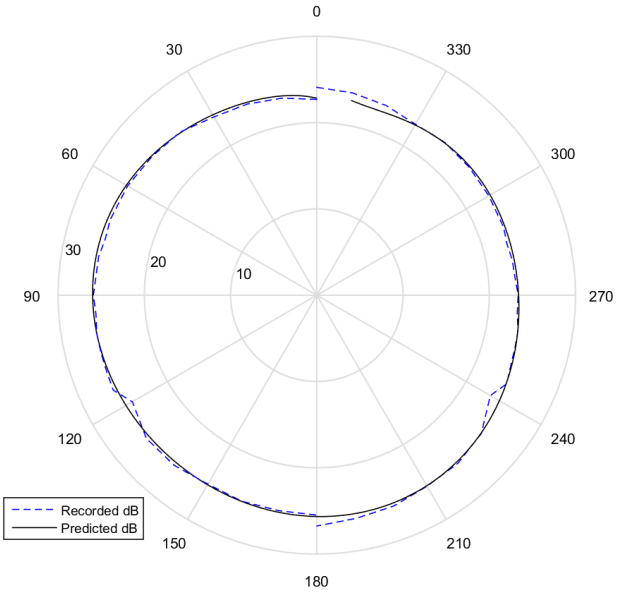


Figure 151. Comparison of Predicted and Recorded Noise Levels for Frequency = 5,039.6842 Hz, Wind Speed = 5.05 m/s



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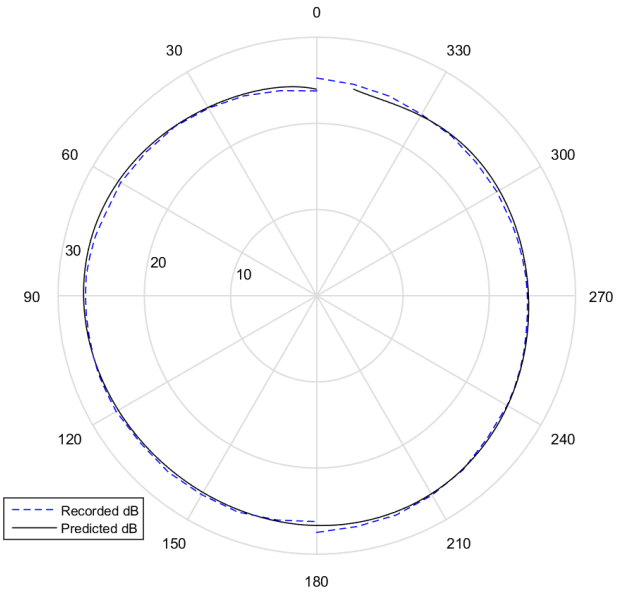
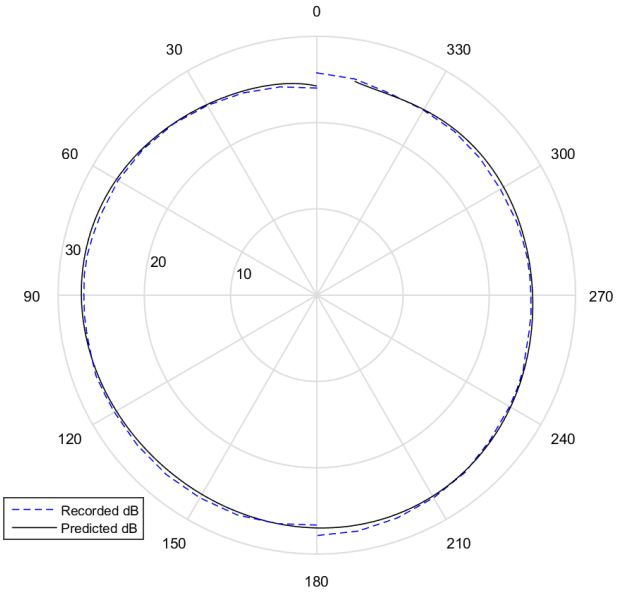


Figure 153. Comparison of Predicted and Recorded Noise Levels for Frequency = 5,039.6842 Hz, Wind Speed = 10.43 m/s



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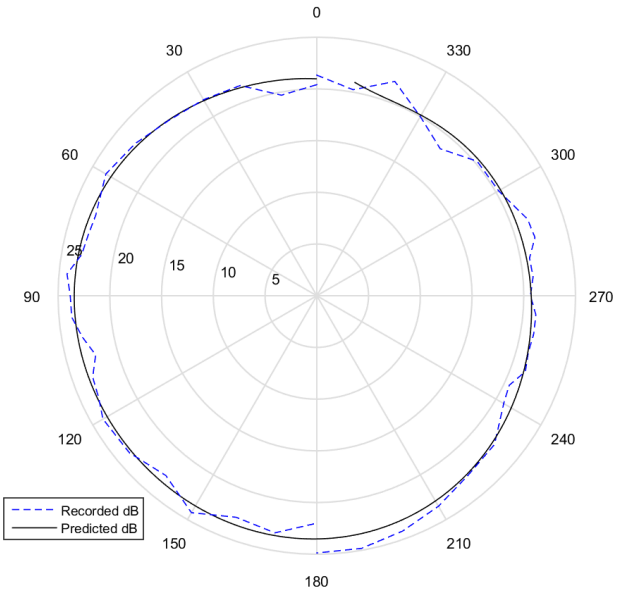


Figure 155. Comparison of Predicted and Recorded Noise Levels for Frequency = 6,349.6042 Hz, Wind Speed = 2.47 m/s

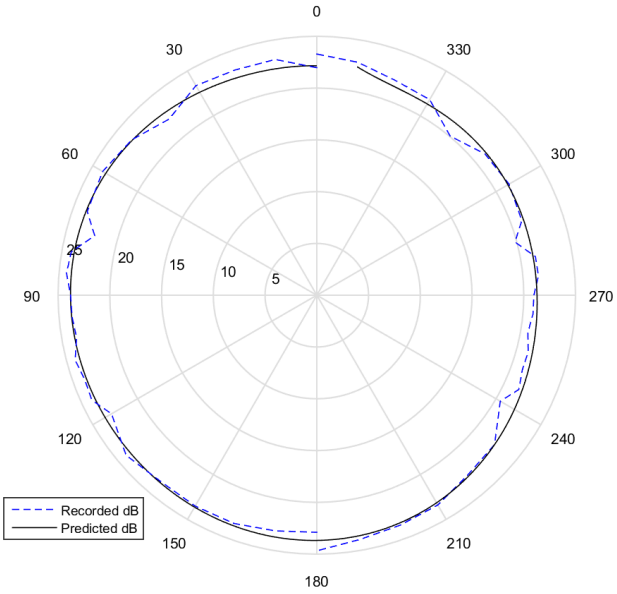
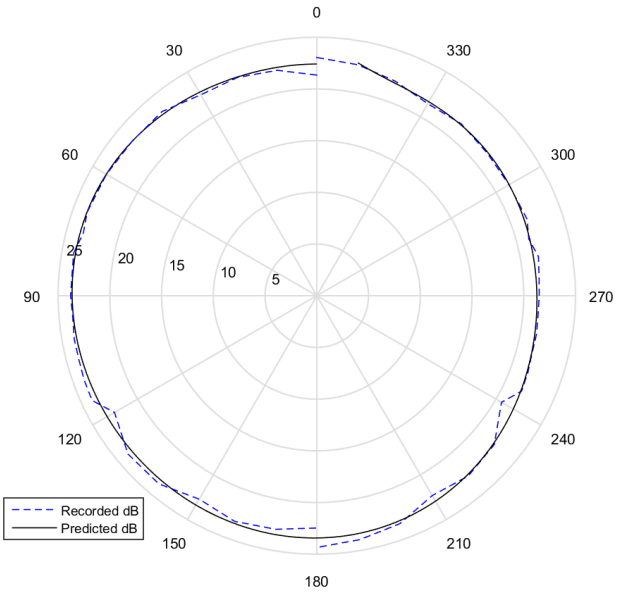


Figure 156. Comparison of Predicted and Recorded Noise Levels for Frequency = 6,349.6042 Hz, Wind Speed = 5.05 m/s



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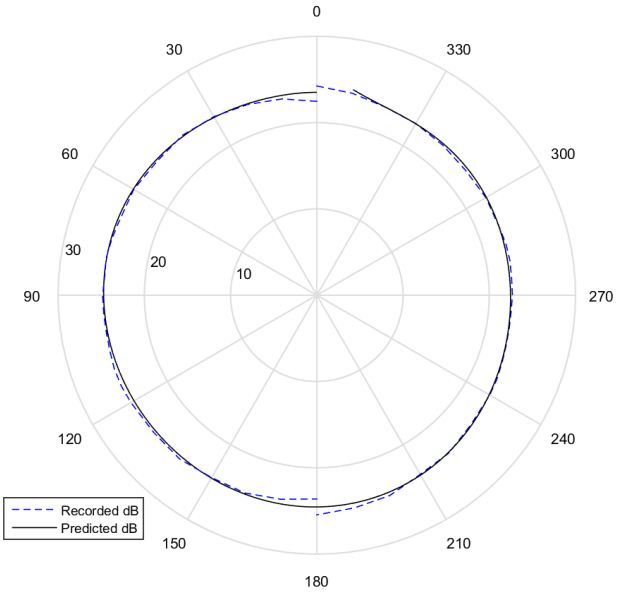


Figure 158. Comparison of Predicted and Recorded Noise Levels for Frequency = 6,349.6042 Hz, Wind Speed = 10.43 m/s

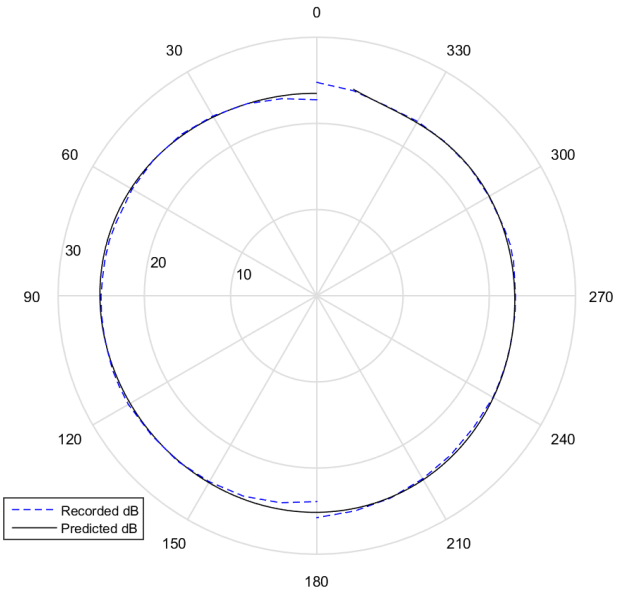


Figure 159. Comparison of Predicted and Recorded Noise Levels for Frequency = 6,349.6042 Hz, Wind Speed = 13.27 m/s

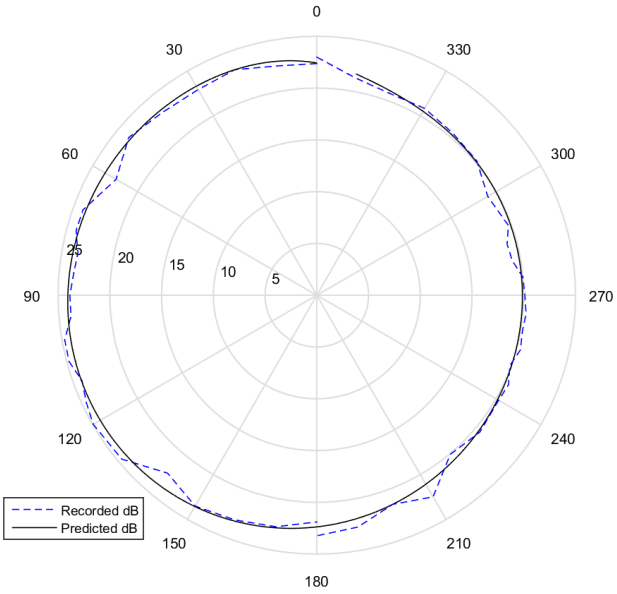
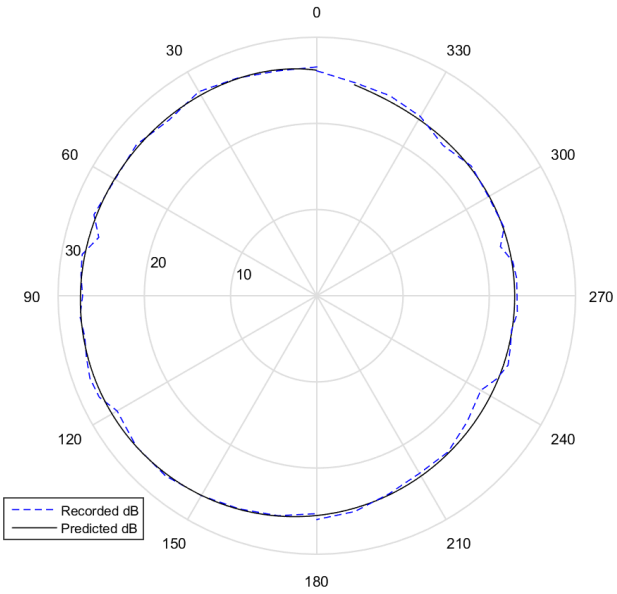


Figure 160. Comparison of Predicted and Recorded Noise Levels for Frequency = 8,000 Hz, Wind Speed = 2.47 m/s



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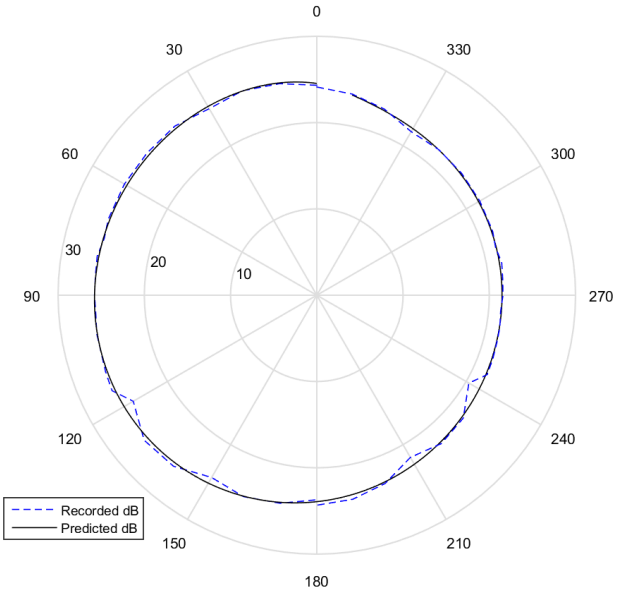

Figure 162. Comparison of Predicted and Recorded Noise Levels for Frequency = 8,000 Hz, Wind Speed = 7.55 m/s

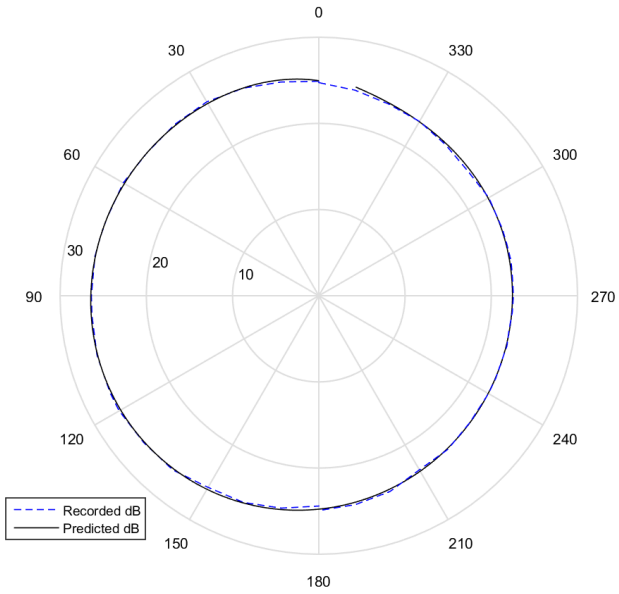

Figure 163. Comparison of Predicted and Recorded Noise Levels for Frequency = 8,000 Hz, Wind Speed = 10.43 m/s

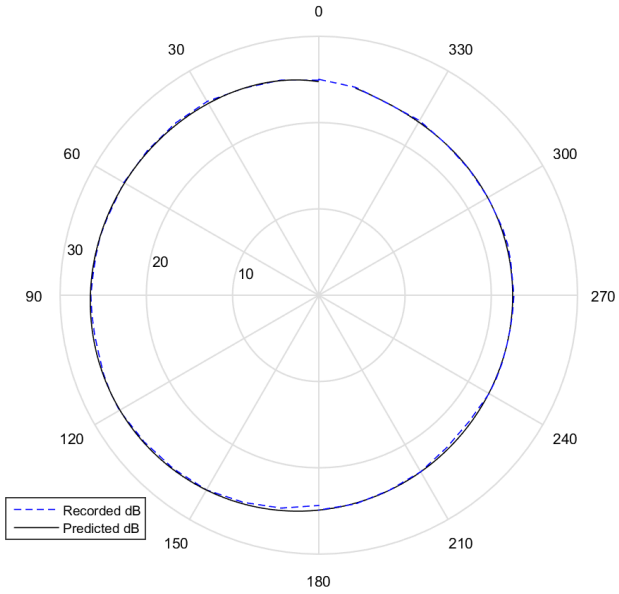

Figure 164. Comparison of Predicted and Recorded Noise Levels for Frequency = 8,000 Hz, Wind Speed = 13.27 m/s

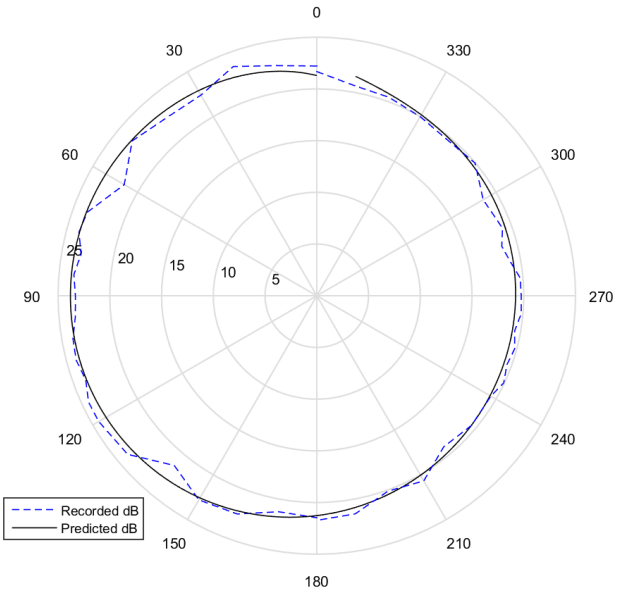

Figure 165. Comparison of Predicted and Recorded Noise Levels for Frequency = 10,079.3684 Hz, Wind Speed = 2.47 m/s

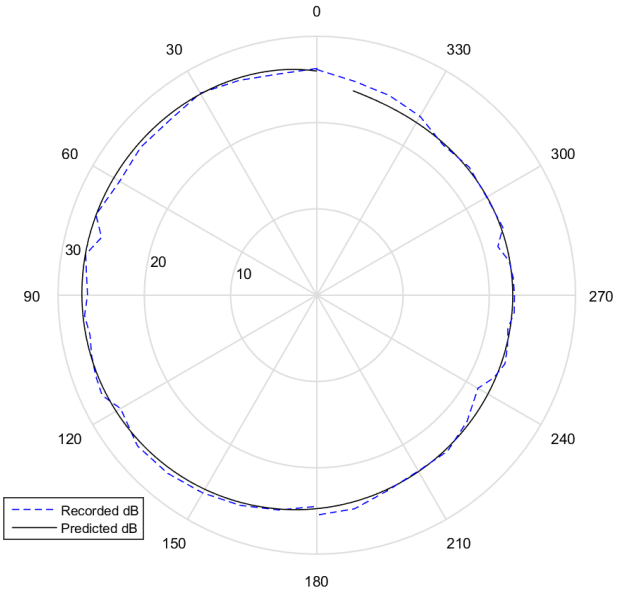

Figure 166. Comparison of Predicted and Recorded Noise Levels for Frequency = 10,079.3684 Hz, Wind Speed = 5.05 m/s

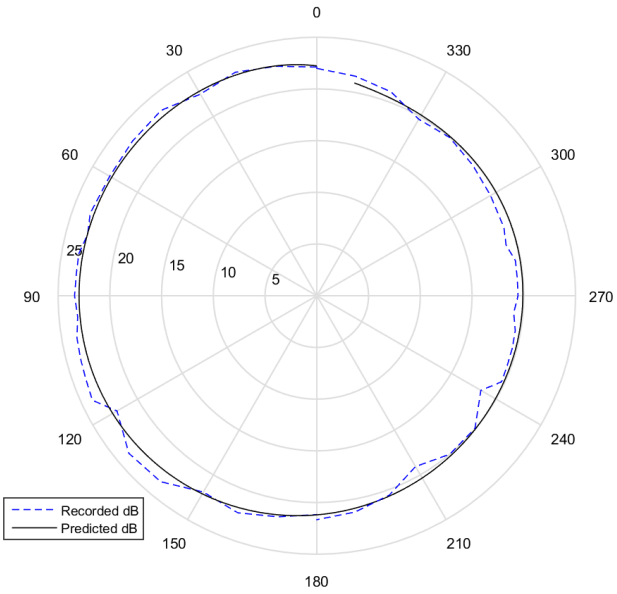

Figure 167. Comparison of Predicted and Recorded Noise Levels for Frequency = 10,079.3684 Hz, Wind Speed = 7.55 m/s

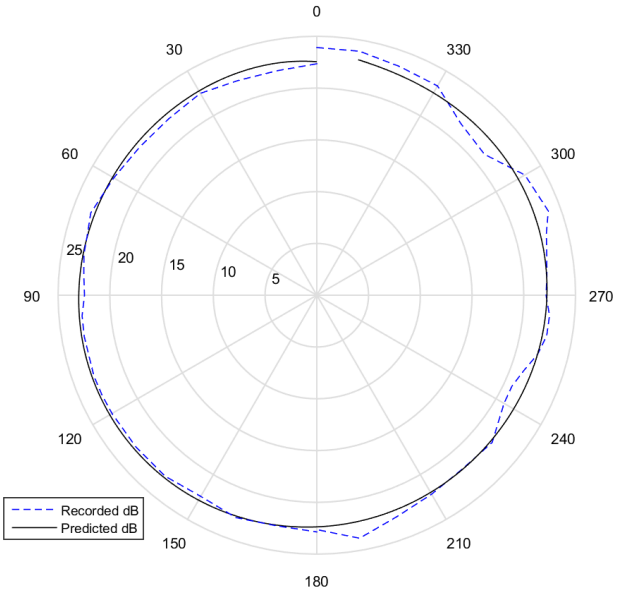

Figure 168. Comparison of Predicted and Recorded Noise Levels for Frequency = 10,079.3684 Hz, Wind Speed = 10.43 m/s

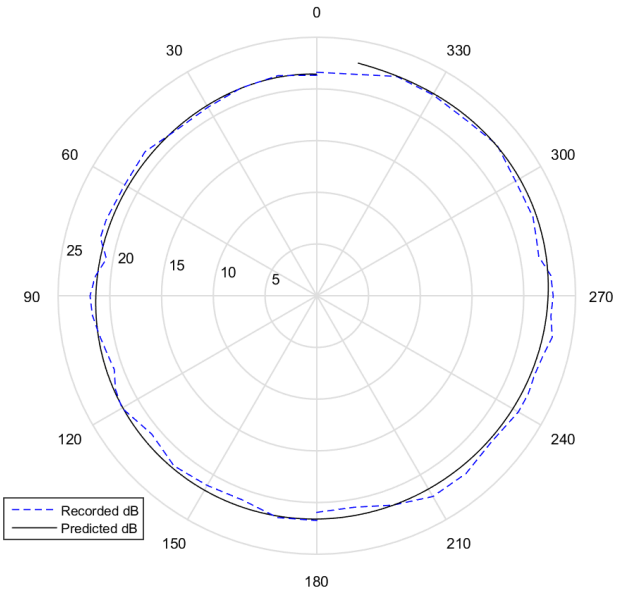

Figure 169. Comparison of Predicted and Recorded Noise Levels for Frequency = 10,079.3684 Hz, Wind Speed = 13.27 m/s

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14. ABSTRACT

The generation of noise caused by wind flowing past a human ear is an important yet vastly understudied factor in determining the ambient noise of an environment experienced by a human observer. Sound level measurements were obtained from wind tunnel tests simulating a human experiencing wind flows at various speeds and from various directions. This data set was used in this thesis. This thesis presents a collection of models for predicting wind noise levels across a broad spectrum of frequencies based on wind speed and angle inputs. Graphical approaches are included to characterize the observed data and illustrate the models' performance.

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