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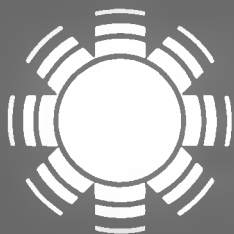
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# Acoustical Measurements of DOE/NASA MOD-0 Wind Turbine at Plum Brook Station, Ohio

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# SERI

**Solar Energy Research Institute**

A Division of Midwest Research Institute

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Golden, Colorado 80401

Operated for the  
**U.S. Department of Energy**  
under Contract No. EG-77-C-01-4042

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**Prepared Under Task No. 1066.70**  
**WPA No. 171**

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## PREFACE

This report documents the results of acoustic measurements made at the DOE/NASA MOD-0 Wind Turbine Generator located at Plum Brook Station, Ohio. These measurements were made as part of the joint SERI/NASA effort to study the acoustic output of utility-sized wind turbines. The machine operating conditions studied closely simulated operation of the larger DOE/NASA MOD-1 wind turbine located in Boone, North Carolina, in both its present downwind configuration and a theoretical upwind mode. The results of these measurements showed that the impulses characteristic of the acoustic output of the MOD-1 wind turbine were visible only during runs at 35 rpm, when the tip speed approaches the tip speed of the MOD-1 at 23 rpm. If any impulses were generated during the MOD-0 23 rpm runs, they were lost in the wind noise at the site. The upwind tests were completely dominated by wind noise, pointing out a limitation of the microphones used in the tests. Work is currently underway to alleviate these problems for future field measurements.

We gratefully acknowledge the cooperation of the NASA Plum Brook staff: Don Cooksey, Hank Pfanner, Charles Martin, and R. "Buck" Rodgers, without whose help this study would not have been possible.

  
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## SUMMARY

### Objective

To monitor the low-frequency acoustic emissions associated with the DOE/NASA MOD-0 Wind Turbine while its rotor operated in the normal position downwind of its support tower and in an upwind configuration.

### Discussion

The DOE/NASA MOD-0 was employed to examine turbine rotor placement as a design criteria for minimizing low-frequency acoustic impulsive noise which has been associated with the larger, MOD-1 turbine in Boone, North Carolina. The ability of the MOD-0 to perform under a wide range of programmable and controllable experimental conditions made it the ideal platform in which to study the effects of various design parameters on the production of acoustic noise.

### Conclusions

Under the available atmospheric conditions, an analysis of the low-frequency acoustic emissions associated with the MOD-0 rotor in its normal downwind position and in a reversed upwind configuration produced some evidence of impulsive acoustic behavior in the downwind mode at 35 rpm; but no such evidence was found at 23 rpm or in the upwind mode at either rotor speed.

**TABLE OF CONTENTS**

	<u>Page</u>
1.0 Introduction .....	1
2.0 Measurement Objectives .....	3
2.1 Background.....	3
2.2 Test Objectives .....	3
3.0 Test Equipment, Procedures, and Conditions .....	5
3.1 Test Equipment .....	5
3.2 Test Procedures.....	5
3.3 Test Conditions .....	6
3.3.1 Downwind Test: 23-26 April 1980 .....	6
3.3.2 Upwind Tests: 15-16 May 1980 and 7-8 October 1980.....	7
4.0 Results .....	9
4.1 Time Analysis .....	9
4.1.1 Downwind Data .....	9
4.1.2 Upwind Data .....	9
4.2 Frequency Analysis .....	12
4.2.1 Background Noise Levels .....	12
4.2.2 Machine Operation — Downwind.....	13
4.2.3 Machine Operation — Upwind .....	17
5.0 Conclusions .....	21
5.1 Factors Influencing Impulsive Behavior .....	21
5.1.1 Background.....	21
5.1.2 Downwind Results .....	21
5.1.3 Upwind vs. Downwind Results .....	22
5.2 Effect of Loads .....	22
5.3 Analysis Limitations .....	22
6.0 References .....	23

**LIST OF FIGURES**

	<u>Page</u>
3-1 Microphone Placement for Downwind Test: 23-26 April 1980.....	7
3-2 Microphone Placement for Upwind Test: 15-16 May and 7-8 October 1980 .....	8
4-1 Representative Time-Pressure History as Measured by Microphone System 3 at 35-rpm Operation in the Downwind Configuration .....	10
4-2 Time-Pressure History for MOD-1 Turbine with Impulsive Noise Present .....	10
4-3 Representative Time-Pressure History as Measured by Microphone System 3 for 23-rpm Operation in the Downwind Configuration.....	11
4-4 Representative Time-Pressure History as Measured by Microphone System 3 for 35-rpm Operation in the Upwind Configuration .....	11
4-5 Representative Time-Pressure History as Measured by Microphone System 3 for 23-rpm Operation in the Upwind Configuration .....	12
4-6 Narrowband Acoustic Spectra of Existing Background under Wind Velocities of 5 and 7 m/s .....	13
4-7 Narrowband Acoustic Spectra of Existing Background for Upwind Test of October 1980 .....	14
4-8 Narrowband Acoustic Spectra for 35-rpm Operation in the Downwind Configuration with the Blade Pitch Fixed at 0° .....	15
4-9 Narrowband Acoustic Spectra for 35-rpm Operation in the Downwind Configuration with the Blade Pitch Fixed at -10° .....	15
4-10 Narrowband Acoustic Spectra for 23-rpm Operation in the Downwind Configuration with the Blade Pitch Fixed at 0° .....	16
4-11 Narrowband Acoustic Spectra for 23-rpm Operation in the Downwind Configuration with the Blade Pitch Fixed at -10° .....	16
4-12 Narrowband Acoustic Spectra for Upwind Rotor Operation at 35 rpm and in the Parked Condition .....	17
4-13 Narrowband Acoustic Spectra for Upwind Rotor Operation at 23 rpm and in the Parked Condition .....	18
4-14 Logarithmically Expanded Narrowband Acoustic Spectra for Upwind Operation at 35 rpm .....	18
4-15 Logarithmically Expanded Narrowband Acoustic Spectra for Upwind Operation at 23 rpm .....	19

## SECTION 1.0

### INTRODUCTION

On 19 April 1980, the Wind Energy Branch of the Solar Energy Research Institute (SERI) submitted a test plan to NASA and DOE to perform a set of acoustic measurements using the DOE/NASA MOD-0 Wind Turbine Generator (WTG), located at Plum Brook Station, Ohio. The purpose of the study was to simulate closely the operation of the MOD-1 WTG located at Boone, North Carolina, under certain operating conditions (e.g., rpm and pitch angle) and with the blade both upwind and downwind of the turbine tower. We intended to measure the effects these operating conditions had on the turbine's acoustic output. The measurements were conducted at three different time periods: 23-26 April 1980; 15-16 May 1980; and 8-9 October 1980. This report documents the results of the acoustic measurements and presents conclusions and suggestions.

The remainder of this report is divided into four sections. Section 2.0 presents the background of SERI noise studies and the purpose of the MOD-0 acoustic measurements. The third section describes the general methodology used to obtain the acoustic data. Section 4.0 discusses the results of the acoustic measurements, and the fifth section presents SERI's conclusions and suggestions.

**SERIO** 

## SECTION 2.0

### MEASUREMENT OBJECTIVES

#### 2.1 BACKGROUND

During the Fall of 1979, as the DOE/NASA MOD-1 WTG near Boone, North Carolina was undergoing a series of engineering shakedown tests, several sporadic and totally unexpected noise complaints were received from homeowners living within a 3-km radius of the installation. These complaints came as a surprise, since a series of earlier conventional noise survey sound measurements, taken at the MOD-0 turbine near Sandusky, Ohio indicated acoustic emissions associated with machine operation were indistinguishable from background at distances greater than 200 m [1].

#### 2.2 TEST OBJECTIVES

As part of the joint NASA/SERI program to study MOD-1 noise and to devise approaches to mitigate the annoyance, SERI, in cooperation with NASA's Plum Brook Test Facility, performed a series of tests at the MOD-0 site. Test procedures closely simulated the operation of the MOD-1 machine under certain controllable operating conditions (e.g., variable rpm and pitch angles) in both upwind and downwind configurations.

The MOD-0 is an experimental machine that gives the operator control of a wide range of machine parameters not easily available on the more operational turbines. These controls make it possible to study the effects of certain specific operating parameters. The test objective was to monitor the acoustic output of the machine in both the upwind and downwind configurations at operating speeds of 35 and 23 rpm, and under various loads to assess the character of the noise produced. The original test plan also called for a simulation of the MOD-2 design (i.e., teetered hub operation and soft tower); however, time did not permit measurements under those conditions.

**SERI** 

## SECTION 3.0

### TEST EQUIPMENT, PROCEDURES, AND CONDITIONS

The acoustic measurements at the MOD-0 WTG were conducted over three periods: 23-26 April 1980; 15-16 May 1980; and 7-8 October 1980. The April tests obtained data with the blades downwind of the turbine tower, while the other two test series were conducted with the machine in the upwind configuration. This section describes the test equipment used and the general procedures employed for all three measurement series.

#### 3.1 TEST EQUIPMENT

A triad of special, low-frequency microphone systems was used in all the tests to collect the major acoustic data. These systems consist of a Bruel & Kjaer (B&K) 2631 carrier system with a B&K 4145 sealed microphone. This configuration records acoustic signals down to 0.1 Hz, although the carrier preamplifiers can detect 0.02 Hz. These microphone systems are used in the SERI Noise Program because of their wide dynamic range, and because they allow preservation of the time-domain phase integrity. (Other microphone systems pick up signals only above 2 to 5 Hz and produce considerable phase distortion below 10 Hz.) The very low cutoff frequency also allows identification of the blade passage frequencies (1.16 Hz at 35 rpm, 0.76 Hz at 23 rpm). In addition to the three low-frequency microphone systems, a B&K Model 2209 sound pressure meter was used for collaborating data.

The output of the four microphone systems, ancillary data, a time code, and voice notes were recorded on a NASA-supplied, IRIG-format, 14-track FM recorder.

The ancillary data recorded included:

- Blade pitch angle
- Blade position (1 pulse per revolution)
- Nacelle yaw position
- Nacelle yaw error
- Rotor rpm
- Generator power
- Nacelle wind speed
- Air temperature.

#### 3.2 TEST PROCEDURES

The acoustic output of the wind turbine was measured by these microphone systems located a nominal 60 m (200 ft) from the base of the turbine support tower and 0.75 m (30 in.) above the ground. The acoustic output of wind turbines is directional with the strongest signal along or slightly off the axis of the wind turbine. Therefore, the microphones were arranged in a triangle at 120-degree intervals to allow measurements close to the turbine axis, regardless of wind direction.

The turbine was operated in the following configurations in both upwind and downwind tests:

- Teetered hub locked out
- Blade pitch angles fixed at -10, -5, and 0 degrees\*
- The above angles at both 23 and 35 rpm
- Generator in both loaded and unloaded status.

The blades in use on the turbine for all three measurement series were fabric-covered "utility pole" blades with tip control.

### 3.3 TEST CONDITIONS

As mentioned above, the acoustic measurements were taken during three time periods, each under different meteorological and machine conditions. A description of these test conditions follows.

#### 3.3.1 Downwind Test: 23-26 April 1980

Acoustic measurements of the MOD-0 with the blades downwind of the support tower were made with the machine running at both 23 and 35 rpm and with the blade pitch angle fixed at -10 and 0 degrees. No -5-degree pitch runs were made during these tests.

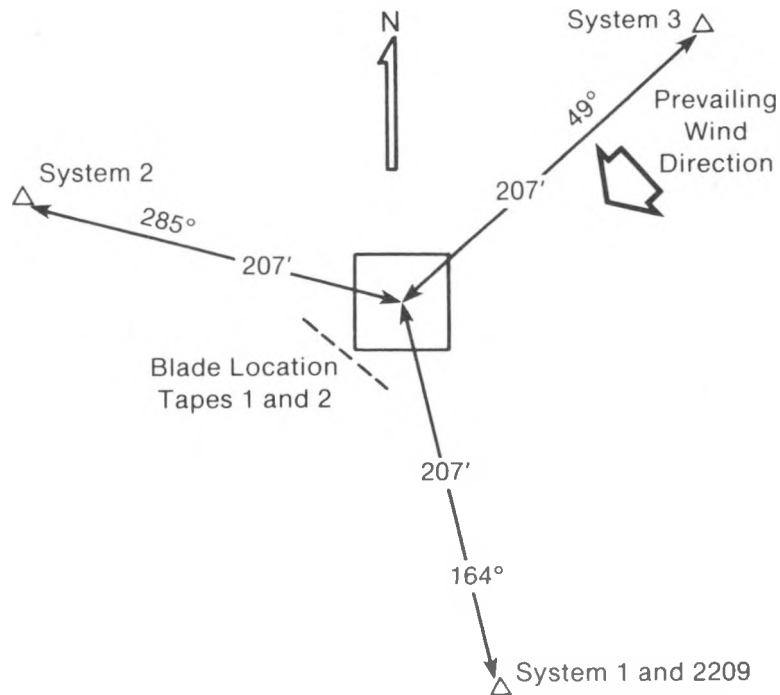
The acoustic data were collected by the microphone systems previously described. For this test, System 3 was on axis and upwind of the turbine. The locations of the microphones are plotted in Fig. 3-1. All acoustic and machine data were recorded on a NASA-furnished recorder (Genisco, Model 10-276) operating in the intermediate-FM band. Due to the high level of very low frequency (below 20 Hz) acoustic energy present during recording, it was necessary to set the upper limit on the low-frequency recording channels rather high (121 dB) to keep saturation of the channels to a minimum. Environmental infrasound recorded probably came from the highly turbulent wind and its effects on the microphones themselves.

The sky was completely overcast with winds from the NNE to NE at 5-9 m/s (13-20 mph) and air temperature of 7.2°C (45°F). The winds, while not particularly strong, were adequate for reasonably steady operation during the 23-rpm runs. The winds became lighter and more variable during the 35-rpm tests, and some intermittent light rain fell. The 35-rpm data, therefore, were not collected under the most steady conditions.

No "thumping" (impulsive sounds) and only a very low "whooshing" sound was noted at 60 m during the 23-rpm tests. An occasional faint thump was noted both outside, downwind of the tower, and in the control room during the 35-rpm runs. The rotor noise was greater during the 35-rpm runs.

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\*Angle convention used at MOD-0 has blade angles running from -90-degree (full feathered) to 0-degree pitch.



**Figure 3-1. Microphone Placement for Downwind Test: 23-26 April 1980**

### **3.3.2 Upwind Tests: 15-16 May 1980 and 7-8 October 1980**

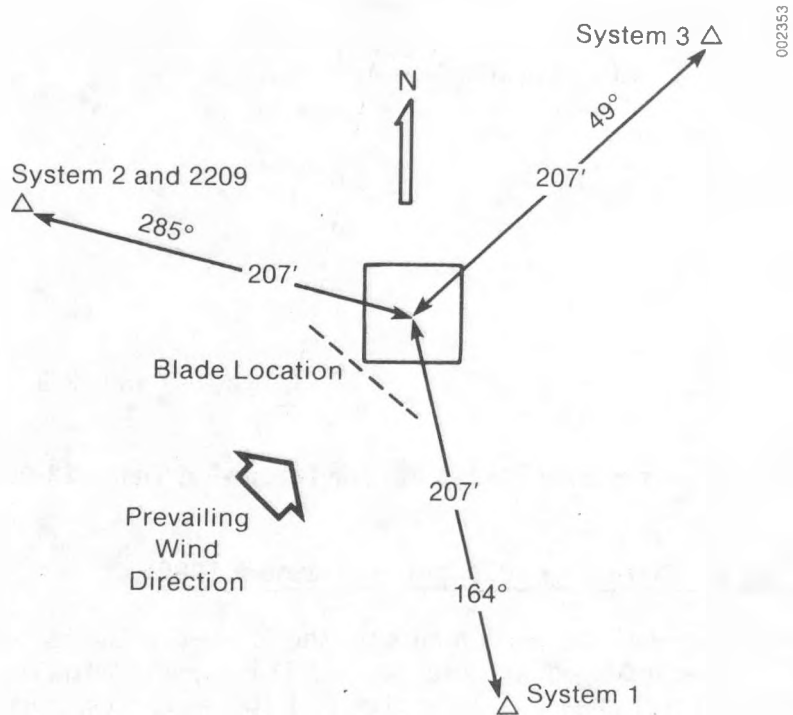
The May series of acoustic measurements at the MOD-0 with the blades upwind of the support tower were conducted at both 35 and 23 rpm, and with the blade pitch angle fixed at -10, -5, and 0 degrees. During this test the wind was from the NW at 5-9 m/s (13-20 mph). SERI field personnel reported that the turbine was very quiet during the test. No thumping was observed, and there was very little aerodynamic (rotor) noise.

When these acoustic tapes were analyzed in the laboratory, nonperiodic "glitches" were discovered on all channels. These very short duration pulses (emanating from an unstable tape recorder power supply) made analysis of the tapes virtually impossible. Because of this problem a second upwind test was conducted in October. These tapes were the only ones analyzed in detail.

Once again measurements were made at both 23 and 35 rpm, and with the blade pitch angle fixed at 0, -5, and -10 degrees. The acoustic data were collected by the same microphone systems. All acoustic and machine data were recorded on a NASA-furnished recorder (Sabre VII) operating in wide-band FM (Group I). Unfortunately, the SERI playback recorder operates only in the intermediate band, and it was necessary to record the tapes from wide band to intermediate-FM band. The re-recording occurred at the NASA-certified, tape-dubbing facility at the Martin Marietta Company in Denver. Once again, there was a high level of very low frequency sound present during recording. While the upper limits on the low-frequency recording channels were set rather high, considerable over-modulation of the carrier systems and tape resulted due to the high level of turbulence characteristic of the Plum Brook site. This distortion hindered analysis of the tapes.

The weather was clear for the entire time of testing, with winds from the SW at 8-10 m/s (18-22 mph) and air temperature of 7.8°C (46°F). The on-axis microphone again was System 3, now downwind of the turbine, as shown in Fig. 3-2. The winds during these tests were adequate for reasonably steady operation at both 23 and 35 rpm.

No impulsive sounds ("thumping") were noted by field personnel during either the 23- or 35-rpm tests. The rotor noise, while quite subdued at all times, was slightly more noticeable during the 35-rpm tests.



**Figure 3-2. Microphone Placement for Upwind Test: 15-16 May and 7-8 October 1980**

## SECTION 4.0

### RESULTS

The acoustic data tapes were analyzed by both time- and frequency-domain methods. Examination of the downwind tapes shows some evidence of periodic impulsive behavior in both the temporal and frequency domains at 35 rpm, but no such behavior at 23 rpm. A high level of ambient noise at the site made detection of the impulses difficult at 35 rpm and impossible at 23 rpm. There is no evidence of impulsive behavior in either the temporal or frequency domain at either speed with the machine in the upwind configuration. As in the downwind tests, there is a high level of ambient background noise, which appears to mask completely the turbine noise at frequencies above 10 Hz. Discrete tones, resulting from unsteady blade loads at the blade passage frequency and its harmonics, are detectable above the wind noise. This section will present the results of the analysis in both the time and frequency domains for both the upwind and downwind tests.

#### 4.1 TIME ANALYSIS

The acoustic tapes were examined in the time domain to locate evidence of impulsive behavior, which occurred only on the downwind tapes recorded during the 35-rpm test. The other test conditions showed no detectable periodic impulsive behavior such as that found at the MOD-1.

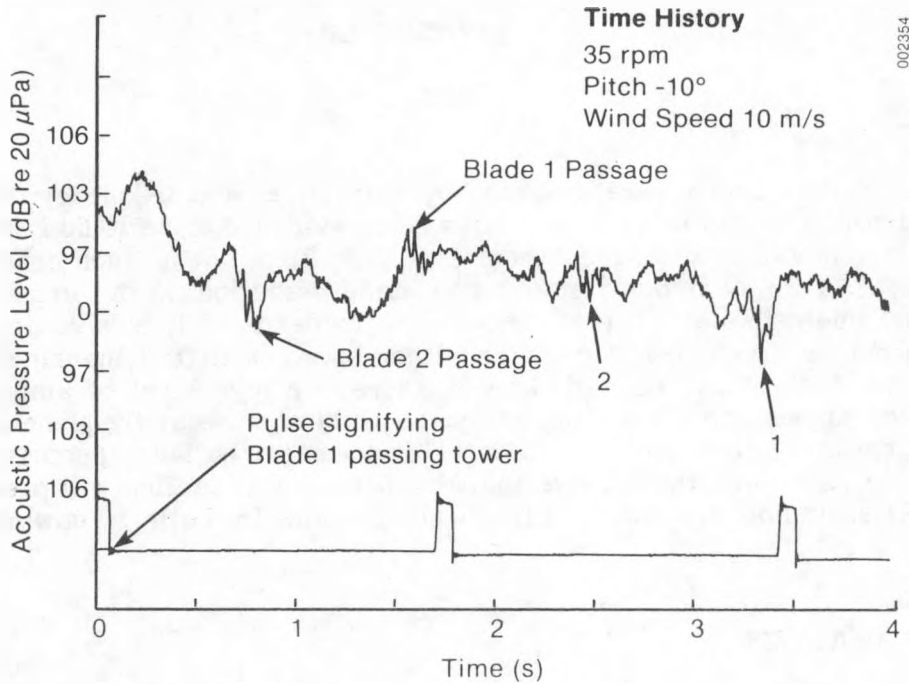
##### 4.1.1 Downwind Data

Figure 4-1 is a representative time history for System 3 when the turbine was operating at 35 rpm. Also shown are the pulses that indicate Blade No. 1 is vertical and behind the tower structure. The time period shown includes five blade/tower passages. There is some evidence of periodic "impulses" or sudden changes in the sound pressure level, though it would be difficult to locate the impulses without the use of the rotor position pulse. The peak overpressure is approximately 94 dB. To compare MOD-0 with MOD-1, Fig. 4-2 shows four blade/tower passages of the MOD-1 at 35 rpm. Here the impulses are clearly visible and the peak overpressure is approximately 104 dB. In addition, the impulses are much sharper in the MOD-1 trace.

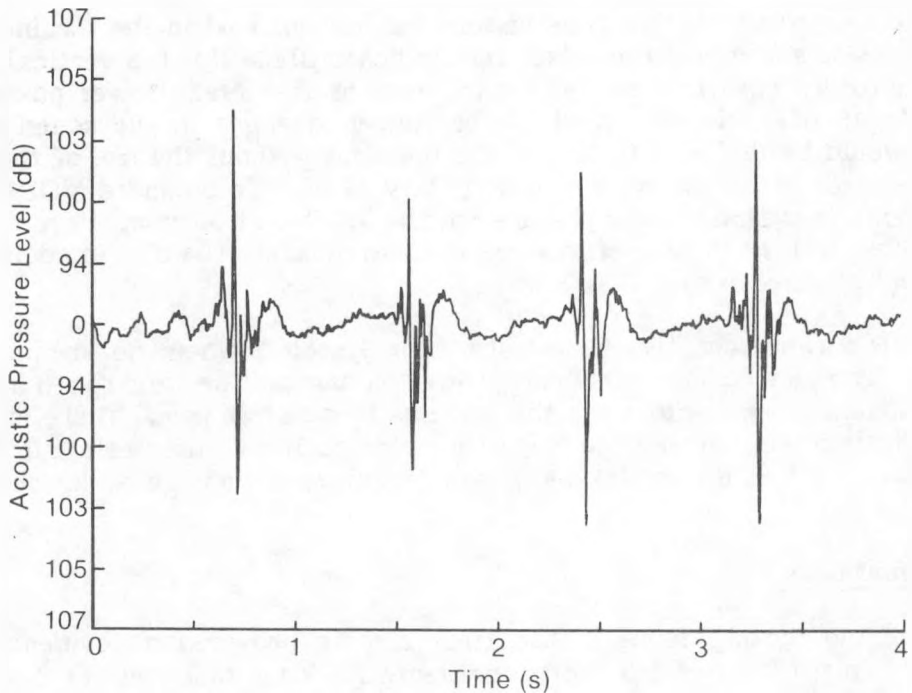
Figure 4-3 is a representative time history for System 3 when the turbine was operating at 23 rpm. The plot covers three blade/tower passages. The wind speed is slightly lower, but other machine parameters are the same as those at 35 rpm. There is no evidence of any periodic impulses, even when using the rotor position pulses as a guide. If impulsive behavior is present, it is completely masked by the wind-induced background noise.

##### 4.1.2 Upwind Data

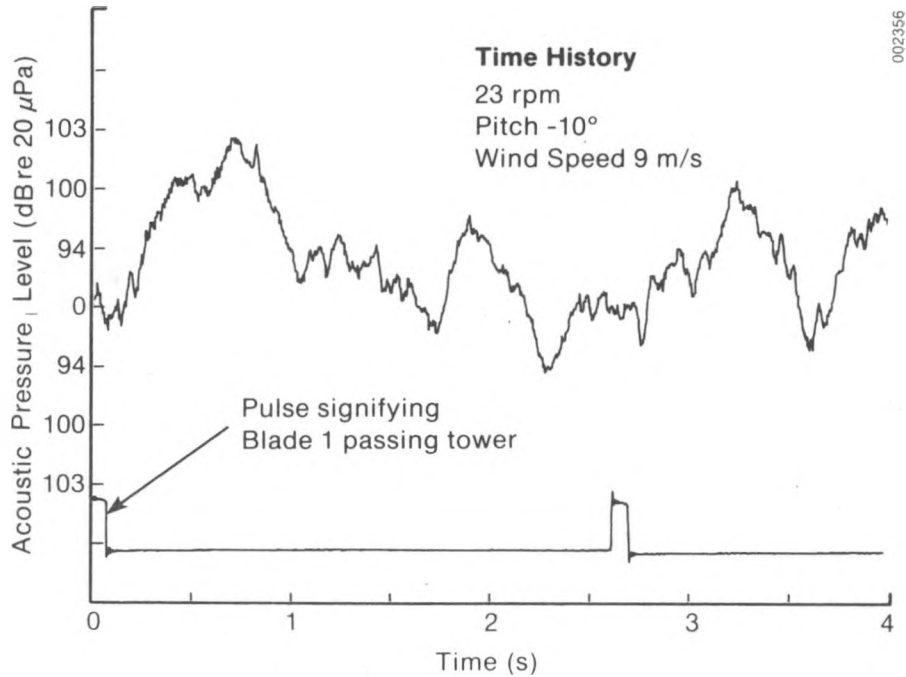
Analysis of the upwind tapes in the time domain provided no evidence of impulsive behavior. Figures 4-4 and 4-5 show representative time histories for System 3 with the turbine operating at 35 rpm and 23 rpm, respectively. No periodic impulsive behavior is evident in either plot, even with the aid of the rotor position pulses.



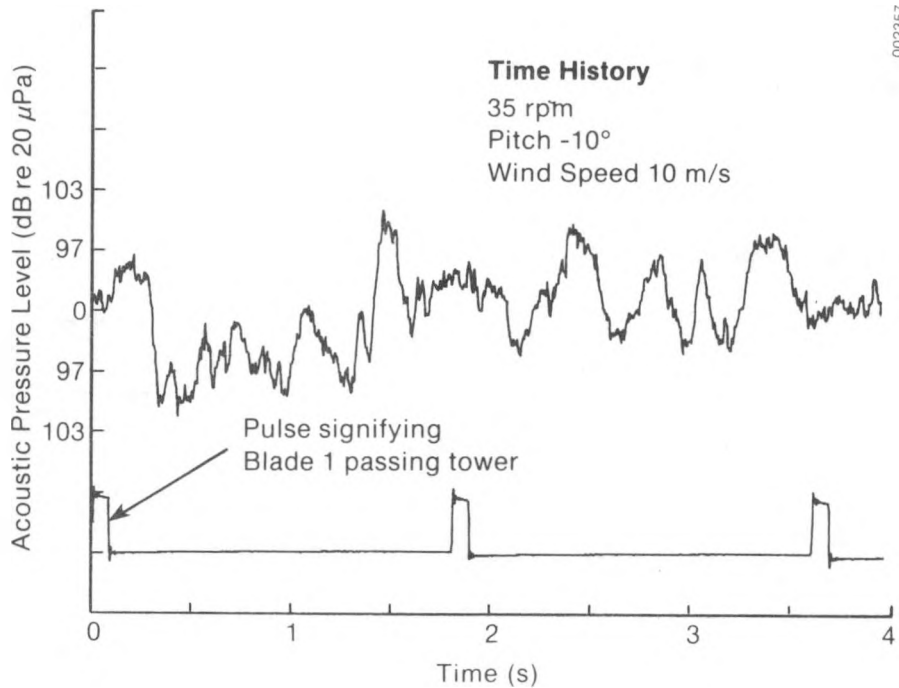
**Figure 4-1. Representative Time-Pressure History as Measured by Microphone System 3 at 35-rpm Operation in the Downwind Configuration**



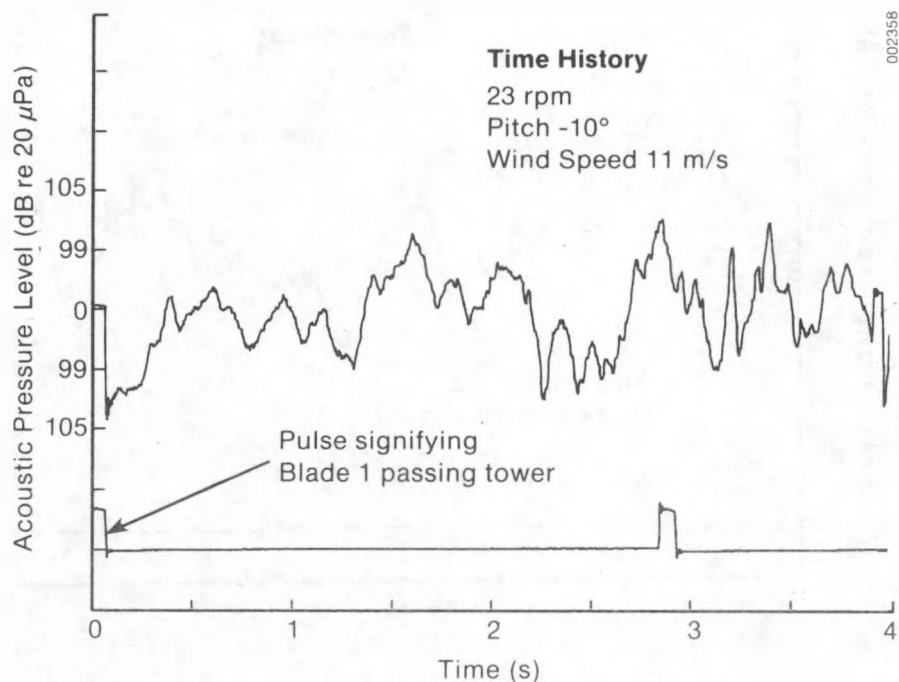
**Figure 4-2. Time-Pressure History for MOD-1 Turbine with Impulsive Noise Present**



**Figure 4-3. Representative Time-Pressure as Measured by Microphone System 3 for 23-rpm Operation in the Downwind Configuration**



**Figure 4-4. Representative Time-Pressure History as Measured by Microphone System 3 for 35-rpm Operation in the Upwind Configuration**



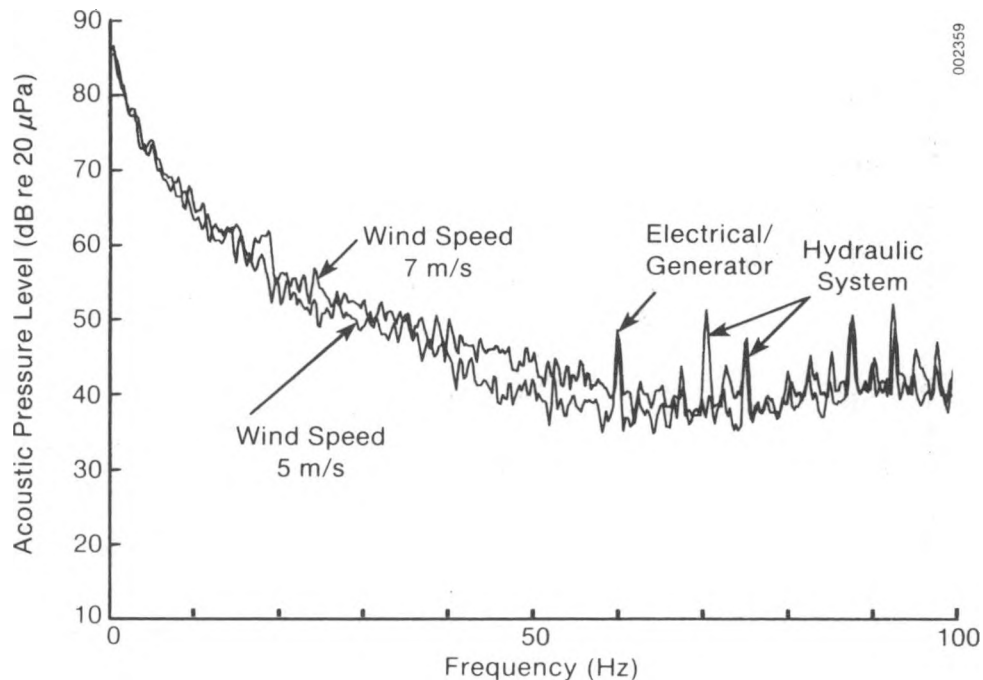
**Figure 4-5. Representative Time-Pressure History as Measured by Microphone System 3 for 23-rpm Operation in the Upwind Configuration**

## 4.2 FREQUENCY ANALYSIS

In the frequency domain, impulsive behavior is evidenced by discrete tones, usually below 50 Hz. These tones make identification of impulsive behavior easy to identify, if they are not obscured by background noises. However, it is necessary to gain some idea of the ambient background noise level to determine other effects of the turbine.

### 4.2.1 Background Noise Levels

The background noise levels at the MOD-0 site are very high, making identification of turbine noises and detection and analysis of impulsive characteristics difficult. Due to time limitations in the field, no systematic background noise measurements were taken. However, during the time when the various microphone systems were being calibrated, the turbine was not turning. Therefore, it was possible to use the period when each microphone was not being calibrated to establish an estimate of the background levels. Figure 4-6 shows frequency plots over the DC to 100 Hz range (effective bandwidth 0.25 Hz) of background noise levels recorded during the downwind tests at two different wind speeds for the on-axis system (System 3). While the turbine was not turning, certain hydraulic systems were in operation, causing the tones at the upper end of the spectra. The discrete tones from the hydraulic system (approximately 70 Hz) can be used as a qualitative gauge of the level of broadband noise present, since these tone levels remain reasonably constant at the fixed microphone distance.



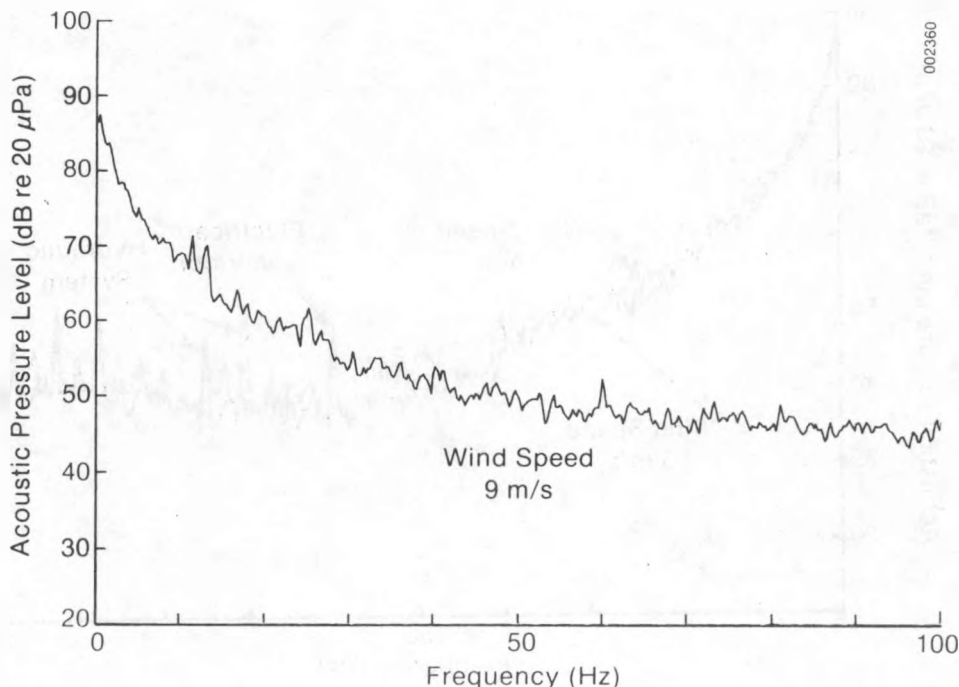
**Figure 4-6. Narrowband Acoustic Spectra of Existing Background under Wind Velocities of 5 and 7 m/s**

Much of the background noise comes from the wind blowing over and around the measuring microphones. Typically, sound surveys are not performed in wind speeds over 5-7 m/s (10-15 mph) to minimize such masking. Standard wind screens (which were used) are optimized for wind velocities below 9.4 m/s (20 mph). Obviously, noise measurements associated with wind turbines will be difficult to make under these conditions, since the turbine operates most efficiently at wind speeds often at or above the maximum recommended at microphone height. To improve representative sound measurements from wind turbines under operating wind conditions, SERI currently is pursuing the development of more effective windscreens.

Figure 4-7 is a similar background plot recorded during the upwind test in October. Figures 4-6 and 4-7 indicate that, on the average, increases in wind speed of 2 m/s result in increases in the background level of 3-5 dB.

#### **4.2.2 Machine Operation — Downwind**

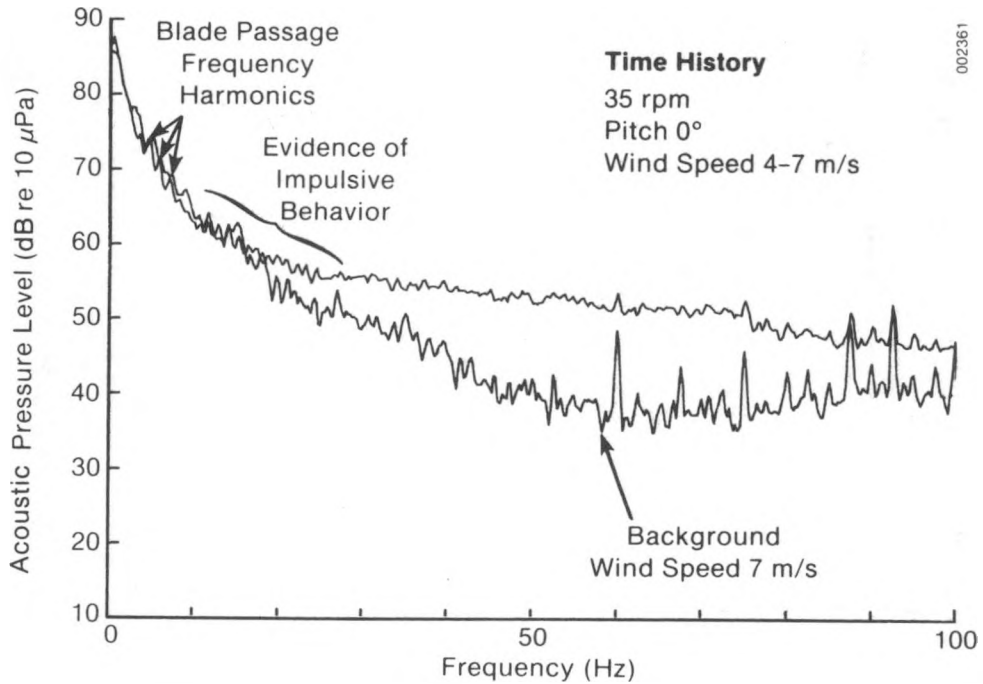
Frequency analysis of the acoustic output of the turbine operating in the downwind configuration shows some evidence of impulsive behavior at 35 rpm but none at 23 rpm, possibly due to the high level of background noise present at the site.



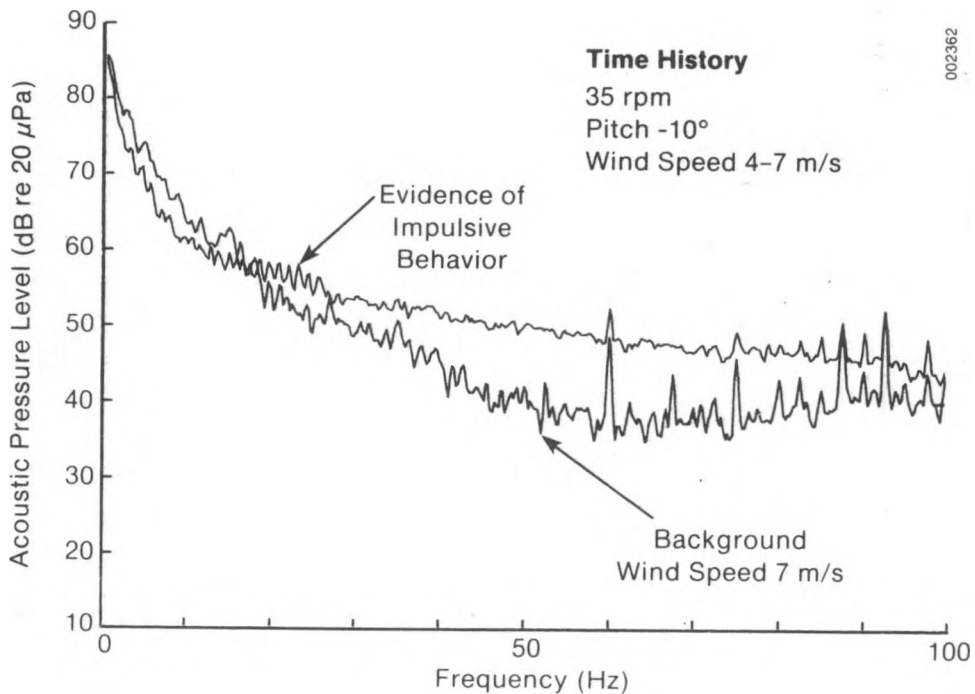
**Figure 4-7. Narrowband Acoustic Spectra of Existing Background for Upwind Test of October 1980**

Figures 4-8 and 4-9 show the spectra when the machine was operating at 35 rpm in a wind speed of 4-7 m/s. With the blade pitch fixed at 0 degrees (Fig. 4-8), there is some evidence of impulses with tones between 10 and 25 Hz. The increased levels over the background above 25 Hz are due to the broadband noise generated by the machine. The hydraulics that were very visible in the background are still visible as small peaks at 60, 75, 85, and 90 Hz. When the blade is fixed at 0-degree pitch, there is a possibility of intermittent stalling which could alter the noise. However, such stalling does not appear to have much effect in this case, due to the time dependency of such effects. Examination of Fig. 4-9 (with the blade pitch fixed at -10 degrees) shows stronger evidence of tones at lower frequencies. There is also evidence of broadband noise and the discrete machine maximas visible at higher frequencies.

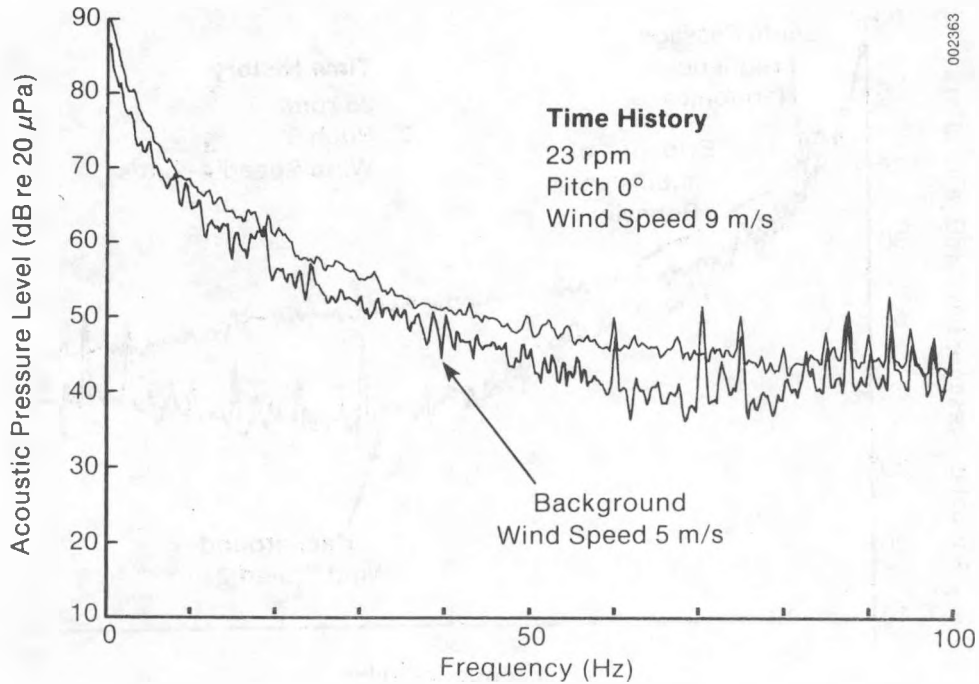
Frequency analysis of the machine's acoustic output when it is operating in the downwind configuration at 23 rpm supports the time-domain analysis. As shown in Figs. 4-10 and 4-11, there is no apparent evidence of impulsive behavior at either fixed pitch angles. The discrete machine peaks are present, but there is no evidence of any broadband noise. The similarity in shape between the background level and levels found during machine operation indicates the spectra are completely wind- and background-dominated. While some evidence exists of machine noises, any impulses generated by the turbine in the downwind configuration at 23 rpm are completely masked by the high background levels.



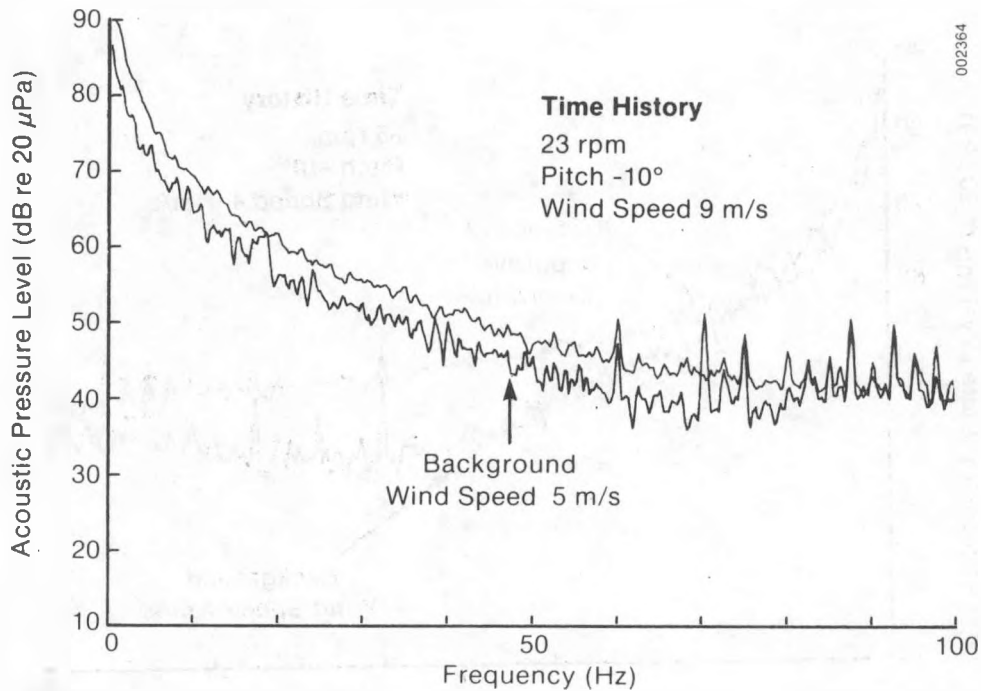
**Figure 4-8. Narrowband Acoustic Spectra for 35-rpm Operation in the Downwind Configuration with the Blade Pitch Fixed at 0°**



**Figure 4-9. Narrowband Acoustic Spectra for 35-rpm Operation in the Downwind Configuration with the Blade Pitch Fixed at -10°**



**Figure 4-10. Narrowband Acoustic Spectra for 23-rpm Operation in the Downwind Configuration with the Blade Pitch Fixed at 0°**



**Figure 4-11. Narrowband Acoustic Spectra for 23-rpm Operation in the Downwind Configuration with the Blade Pitch Fixed at -10°**

### 4.2.3 Machine Operation — Upwind

Frequency analysis of the acoustic output of the turbine while in the upwind configuration showed no evidence of impulsive behavior at either 23 or 35 rpm, supporting the conclusions from the time analyses. Figures 4-12 and 4-13 show representative frequency plots (effective bandwidth 0.25 Hz) of machine operation at -10-degree pitch and both 35 and 23 rpm, respectively, as recorded by System 3, along with estimated background levels. None of the discrete tone characteristics of periodic impulsive behavior were apparent; indeed, there is no evidence of any of the machine discretions at the higher frequencies that were present in the downwind plots resulting from the blades passing through the tower shadow. The lack of machine discretions and the similar shape of the machine operating plot and the background spectra imply that the tapes are completely dominated by wind and background noise. The results are the same for the -5- and 0-degree fixed pitch runs.

Evidence of machine operation at the lower frequencies was located by using a log frequency plot from DC to 50 Hz (effective bandwidth 0.125 Hz). In both the 35-rpm run (Fig. 4-14) and the 23-rpm run (Fig. 4-15), the fundamental blade-passage frequencies (BPF) are evident. Above 8-10 Hz the spectra appears to be completely dominated by wind noise, which explains the similarity between the two spectral lines shown in Figs. 4-12 and 4-13. The few BPF harmonics appearing in these plots are most likely the result of the blades cutting through the vertical shear within the rotor disk.

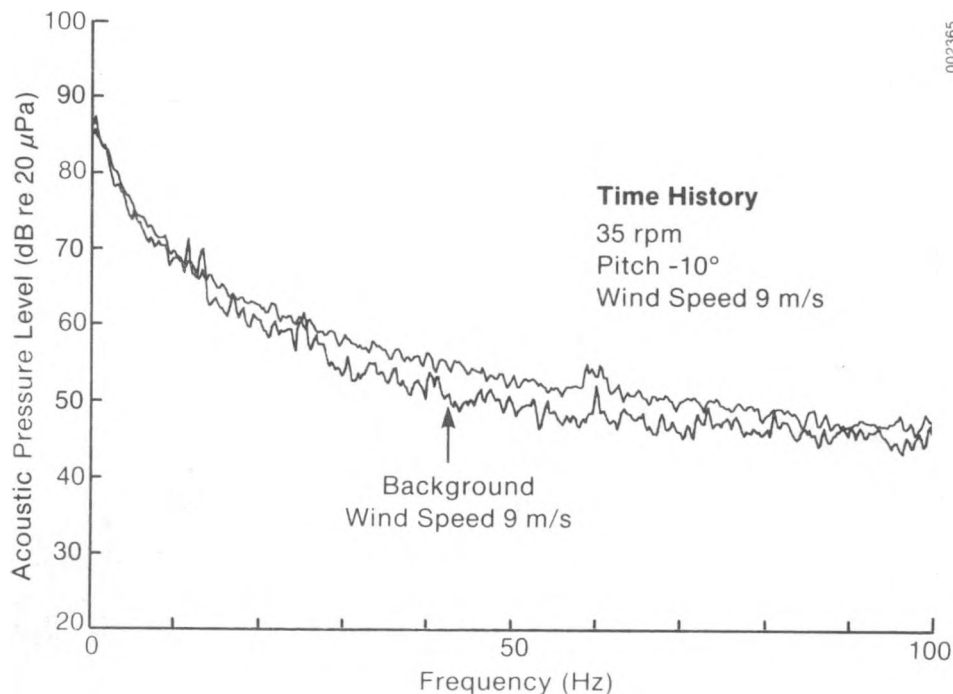
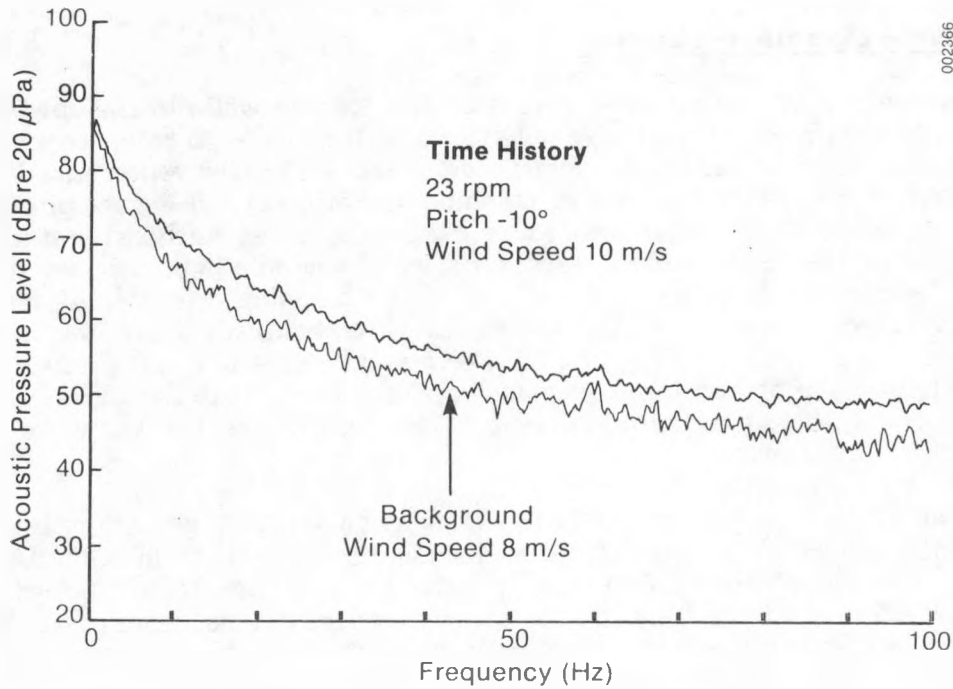
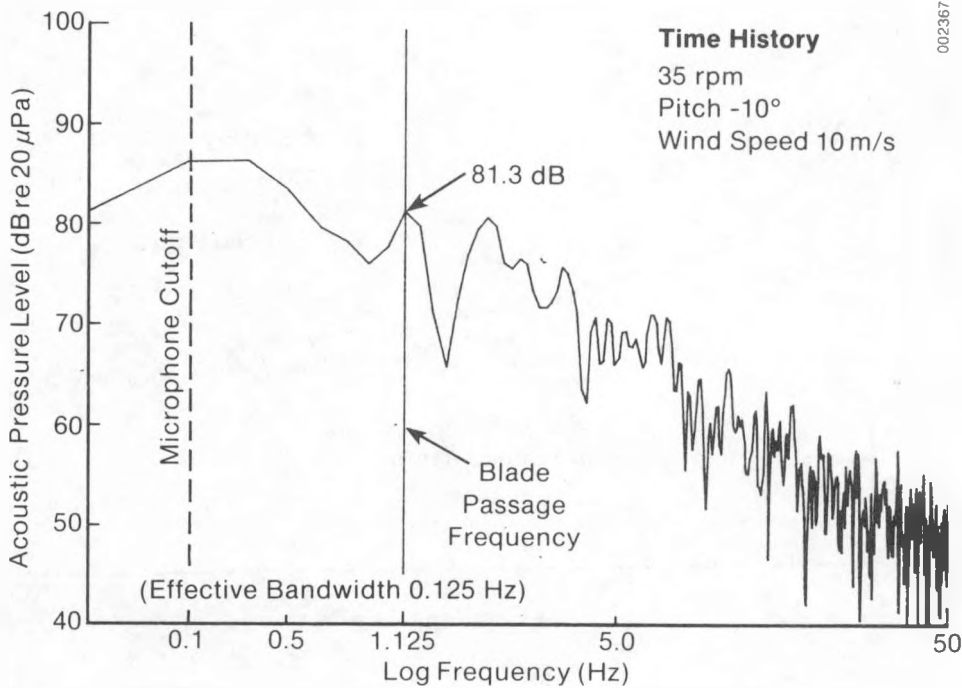


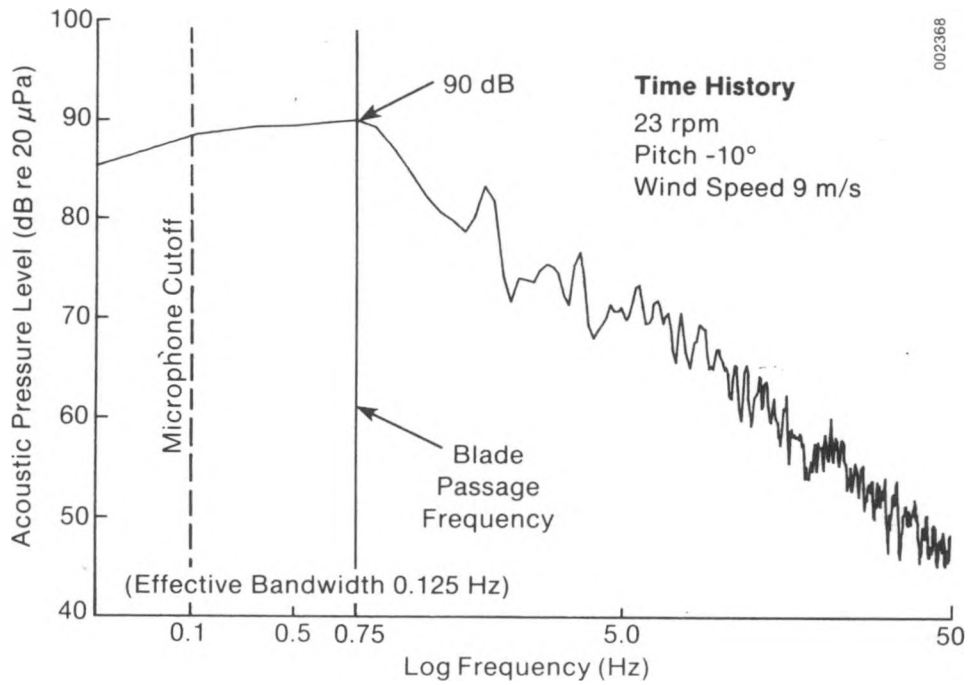
Figure 4-12. Narrowband Acoustic Spectra for Upwind Rotor Operation at 35 rpm and in the Parked Condition



**Figure 4-13. Narrowband Acoustic Spectra for Upwind Rotor Operation at 23 rpm and in the Parked Condition**



**Figure 4-14. Logarithmically Expanded Narrowband Acoustic Spectra for Upwind Operation at 35 rpm**



**Figure 4-15. Logarithmically Expanded Narrowband Acoustic Spectra for Upwind Operation at 23 rpm**

**SERIO** 

## SECTION 5.0

### CONCLUSIONS

The analysis of the acoustic measurements made at the MOD-0 site with the turbine blade both upwind and downwind of the support tower produced some evidence of impulsive behavior in the downwind configuration at 35 rpm, but no such evidence at 23 rpm or in the upwind configuration. The factors influencing these results, the effect of differing blade loads on the sound output, and some limitations of the analysis methods are discussed in this section.

#### 5.1 FACTORS INFLUENCING IMPULSIVE BEHAVIOR

##### 5.1.1 Background

The impulsive nature of the acoustic output of some wind turbines, most notably the MOD-1 in Boone, North Carolina, is believed to be the direct result of the interaction of the blades and unstable vortex flows in the wakes of the support tower legs. Evidence both confirms the existence of energetic vortex flows that are essentially two-dimensional, and suggests that upstream turbulence may have considerable influence over the degree of wake instability and the level of impulse sounds produced by the turbine [2].

##### 5.1.2 Downwind Results

The analysis performed on acoustic tapes made with the MOD-0 WTG blades downwind of the support tower showed that some acoustic impulsive behavior is present when the turbine is operating at 35 rpm. At 23 rpm there is no detectable impulsive behavior in its acoustic output. (At the MOD-1 site, impulsive behavior dominates the acoustic signal.)

The main reason for the low visibility of the impulses (compared to MOD-1) appears to be related to the blade-tower clearance and the relative blade velocities. Roshko [3] has shown that the most energetic part of the wake (from a discrete energy point of view) extends from about 2 to 10 diameters downstream of a cylinder. The MOD-1 minimum leg-to-blade clearance is 4 tower leg diameters (2 m) as the blade passes on a corner of the tower. If the blade passes on a side of the tower, the leg-to-blade distance is 7 to 8 leg diameters, still in the energetic part of the wake. At MOD-0, the minimum leg-to-blade clearance is 15 tower-leg diameters (3 m), where the wake flow is likely to be less energetic and organized. Thus, the periodic, unsteady loads seen by the MOD-0 blades are much less severe than those seen by the MOD-1.

The tip velocity of the MOD-0 at 35 rpm (70 m/s) only approaches the tip velocity of the MOD-1 at 23 rpm (71 m/s). At 23 rpm, the MOD-0 has a tip velocity half that of the MOD-1 at 35 rpm (46 m/s for the MOD-0 at 23 rpm, 108 m/s for the MOD-1 at 35 rpm). Thus, when cutting through the less energetic wake at a greatly reduced speed, it is possible that either no impulses are generated due to the increased residence time or that those generated have a small amplitude and may not occur with every blade passage.

If the latter is true, then the zero visibility probably is due to the high background noise levels present at the site. High background levels could also be responsible for the lack of broadband noise and the limited visibility of the machine discretions. The wind speeds were higher during the measurements at 23 rpm than those at 35 rpm. Thus, the run with (probably) less machine noise had a higher background level. It is possible that if the microphones had been located closer than 60 m, more detail in the acoustic output could have been picked up.

### **5.1.3 Upwind vs. Downwind Results**

The analysis of acoustic tapes made with the MOD-0 WTG blade upwind of the support tower found no evidence of periodic impulsive behavior when the turbine was operating at either 23 rpm or 35 rpm. When the blades pass upwind of the tower, there is no organized two dimensional and short wavelength flow to interrupt the loading on the blades, hence no periodic loading of the blades and no impulsive behavior.

While no impulse behavior could be found on the upwind test tapes, it was not possible to document the acoustic output of the machine above 8-10 Hz, due to the predominance of wind-induced noise at the site.

## **5.2 EFFECT OF LOADS**

It has been established, based on work at the MOD-1 WTG, that impulse amplitudes generated by blade-tower wake interactions are not electrical output power dependent [2]. Broadband noise from wind turbines, however, is a function of blade pitch angle, inflow turbulence, and hence, power. Certain noise prediction models have estimated a slight (2-6 dB) increase in broadband sound pressure level with increases in power for the MOD-1 [4]. This effect could not be seen in the MOD-0 tests, chiefly because of the high level of background noise.

## **5.3 ANALYSIS LIMITATIONS**

Broadband and wind noise are random variables, and their mean values vary with time; therefore, the acoustic output of a wind turbine can change radically from one blade passage to the next. Using average spectra to analyze this type of noise is probably not the best method, as the averaging process tends to smooth out random variations that may be important to an understanding of the acoustic generation process of the turbine. SERI currently is developing an analytic method based on probability distributions for use with future data sets. Due to its limitations the current acoustic data set will not be analyzed further.

**SECTION 6.0****REFERENCES**

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