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THE EFFECTS OF BLADE MOUNTED VORTEX GENERATORS ON THE NOISE FROM A MOD-2 WIND TURBINE GENERATOR

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UTTL: The effects of blade mounted vortex generators on the noise from a MOD-2 wind turbine generator

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ABS: Comparison noise measurements were made for a standard MOD-2 machine and for one modified to include an array of vortex generators on the suction sides of the blades near maximum thickness. Data were obtained for comparable azimuth angles and distances for a range of wind velocities of 7.6 to 10.3 m/s and for power outputs of 1.4 MW. Since the observed differences are small it is concluded that the inclusion of vortex generators on this machine will result in no significant increase in environmental impact due to noise.

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INTRODUCTION

Recent studies have indicated that the use of vortex generators on the blades of the MOD-2 wind turbine generator results in improved aerodynamic performance. The purpose of this paper is to report the results of a brief measurement study to compare the noise radiation of the MOD-2 machine with standard blades and with blades modified to include an array of vortex generators. Data are included for normal values of power generation, wind velocity and ambient temperature.

This effort is part of the Department of Energy wind energy program which is managed by the NASA Lewis Research Center. The MOD-2 machine was built under contract to NASA by the Boeing Engineering and Construction Co., and the utility selected to participate in the operational portion of the program is the Bonneville Power Administration.

APPARATUS AND METHODS

Description of Site

The wind turbine site at which noise measurements were made is at Goodnoe Hills near Goldendale, WA. The installation consists of three MOD-2 machines on a rounded promontory on the north edge of the Columbia River gorge at a nominal elevation of 884 m (2900 ft). The recorded data for this paper were obtained from operations of machine no. 3 (Figure 1.)

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Description of Wind Turbine

The MOD-2 wind turbine has a two bladed 91.4 m (300 ft) diameter rotor mounted on a 61 m (200 ft) high, 3 m (10 ft) diameter (circular cross section) tower (Fig. 2). It is an upwind machine with a maximum power rating of 2.5 MW and an operational range of wind velocities from 6.7 to 19.7 m/sec (15 to 44 mph). The outer 14 m (46 ft) section of each blade is movable in pitch angle and is adjusted by a hydraulic control system. Precise rotational speed control is maintained to provide an rpm of 17.5. Blades are tapered in chord from 1.43 m (4.7 ft) at the tip section (NACA 23012 airfoil) to 4.3 m (14.1 ft) at the root (NACA 23028 airfoil). Rotor blades have a built-in twist of 8 degrees, a total area of about 280 m^2 (3000 ft^2) and a rotational tip speed of 83.8 m/sec (275 ft/sec).

A computer control system is provided to monitor the wind velocity and direction, to bring the machine on line when the wind velocity exceeds a minimum value, to determine the optimum blade angle setting during normal operations, and to take the machine off line when the wind velocity falls below the minimum or when it exceeds the maximum allowable value.

Two configurations were tested: one having standard blades and the other having an array of vortex generators applied to each blade. Some details of the latter configuration are illustrated by the photographs of Figure 2. The inset photo shows a single element approximately 8 cm long by 2 cm high. Pairs of these elements are applied at about one foot intervals along the suction side of the blade at its maximum thickness from the 40% radius station to the tip. Visible in the photograph of Figure 2 are those from the 40% station to the movable tip section (70% station).

Wind Turbine Operating Conditions

For all data reported herein the prevailing wind direction was west, the mean wind velocity range was from 7.2 to 14.4 m/sec (16 to 32 mph) and the temperature range was 22°C to 39°C. All data were recorded on 8 July 1983 between 1620 and 1730 hours, and on 8 August 1983 between 1800 and 2250 hours.

Wind velocity and wind direction data were monitored and recorded continuously from meteorological instruments located near the height of the rotor hub. Example time histories of wind velocity and direction are shown in Figure 3 along with a time history of electrical power output of the MOD-2 machine. The variations indicated in Figure 3 represent those existing at the times of the tests for which data are reported herein.

Noise Measurements

All noise measurements were made with commercially available battery powered instrumentation. One-half inch diameter condenser microphones with a usable frequency range 3-20,000 Hz were used with a two channel direct recording machine which provides a useful dynamic range of about 60 dB in the frequency range of 25 Hz to 20,000 Hz. This system provided high dynamic range recordings for direct playback in frequency analyses. Spectral data were obtained with the aid of conventional one-third octave band and narrow band analyzers.

The measurement locations are shown in Fig. 4. These included a near field location under the hub and far field locations upwind, downwind and crosswind. The measurement distance of 150 m (approximately 1.5 rotor diameters) was chosen to represent far field conditions with minimum wind gradient effects and maximum signal to noise ratios.

To minimize the detrimental effects of wind noise, polyurethane foam microphone wind screens were used and microphones were placed on the ground surface, where wind velocities were relatively low.

RESULTS AND DISCUSSION

Noise data presented herein were obtained from measurements made with direct tape recordings in both the near and far acoustic fields. Data are presented in the form of A-weighted L_{EQ} levels, one-third octave band frequency spectra, and narrow band frequency spectra.

A-Weighted Sound Pressure Levels

Magnetic tapes were played back into a community noise analyzer in order to compare the A-weighted energy average sound levels. Results are given in the table below.

Measurement Location	A-weighted Noise Levels (L_{EQ})		
	V=7.6 - 10.3 m/s		V=12.5 - 14.3 m/s
	Standard	Modified	Modified
0°	57.1 dB	57.9 dB	59.4 dB
90°	56.7	57.5	59.7
180°	58.8	59.0	58.3
270°	61.7	60.2	62.5
Near Field	74.6-76.8	75.8	77.5

Note that both far field and near field data are included for two ranges of wind velocities. Numbers in the table represent approximately 2-minute averages, on an energy basis, of the A-weighted levels. Of particular interest is the direct comparison of the data for the standard and modified machines at the lower wind velocity conditions. Operating conditions are nominally the same but are subject to the variations suggested by the wind and power time histories of Figure 3. Relatively small differences between the standard and modified machines are noted, and these differences can be accounted for by temporal changes in operating conditions. Comparisons of the data sets for two different ranges of wind velocity indicate that the higher noise levels are associated with the higher winds and power output.

One-Third Octave Band Spectra

Broad band spectral data are shown in Figures 5 and 6 (a) through (d). In each case the standard machine results are compared with those for the modified machine at the same nominal operating conditions. The data of Figure 5 indicate that the two near field spectra are similar in shape but that some differences in levels exist. The same general conclusion can be drawn from the far field spectra of Figure 6. The most consistent differences however involve the broad band peak in some of the spectra in the frequency range 2 kHz - 10 kHz. These enhanced high frequency noise levels may be due to the application of vortex generators, but would not be important at large distances because of the increased atmospheric losses involved at these higher frequencies.

Narrow Band Spectra

Magnetic tape recordings were analyzed on a narrow band basis (Δf=12.5 Hz) to determine the existence of discrete frequency components and to emphasize existing differences in the lower frequency portions of the spectra. These results are shown for the near field in Figure 7 and for the far field in Figure 8 (a) through (d). In each case spectra presented are for the standard and modified machines at the same nominal wind velocity and power output ranges. The results are consistent with those of the table and Figures 5 and 6. The measured noise level differences are judged not to be significant.

CONCLUDING REMARKS

Comparisons of noise level measurements for a standard MOD-2 wind turbine generator and for one in which an array of vortex generators had been applied to the blades revealed no significant differences. Measurements relatively close to the machine but in the far acoustic field indicate small noise level increases at the higher frequencies that may be due to the vortex generators. At the greater distances significant for community exposures, the atmospheric propagation losses would probably nullify the above differences. It is therefore concluded that the application of vortex generator to the MOD-2 machine will have a negligible adverse effect on its environmental noise.

Figure 1. - Photograph of MOD-2 Wind Turbine Generator for which Data are Presented

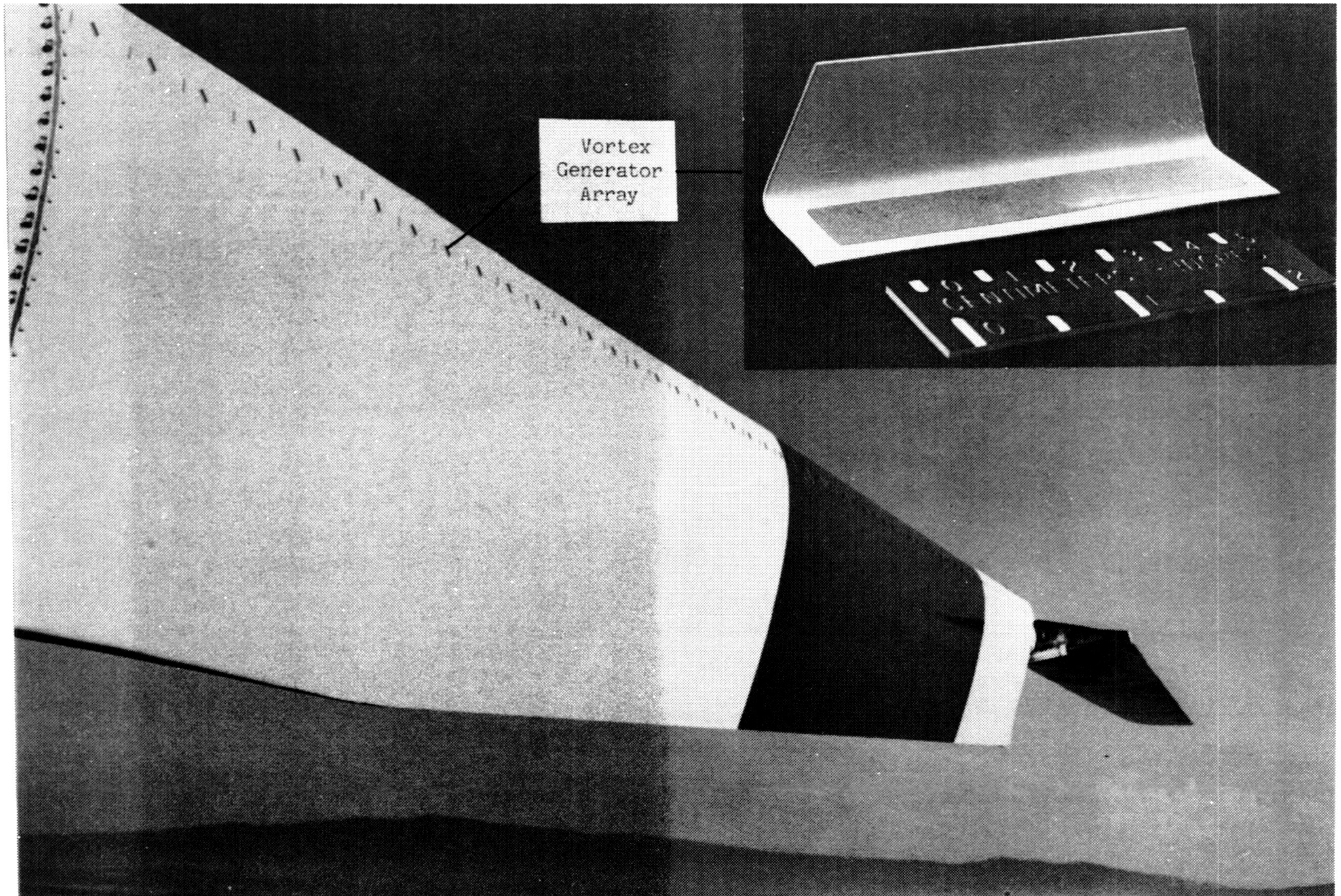
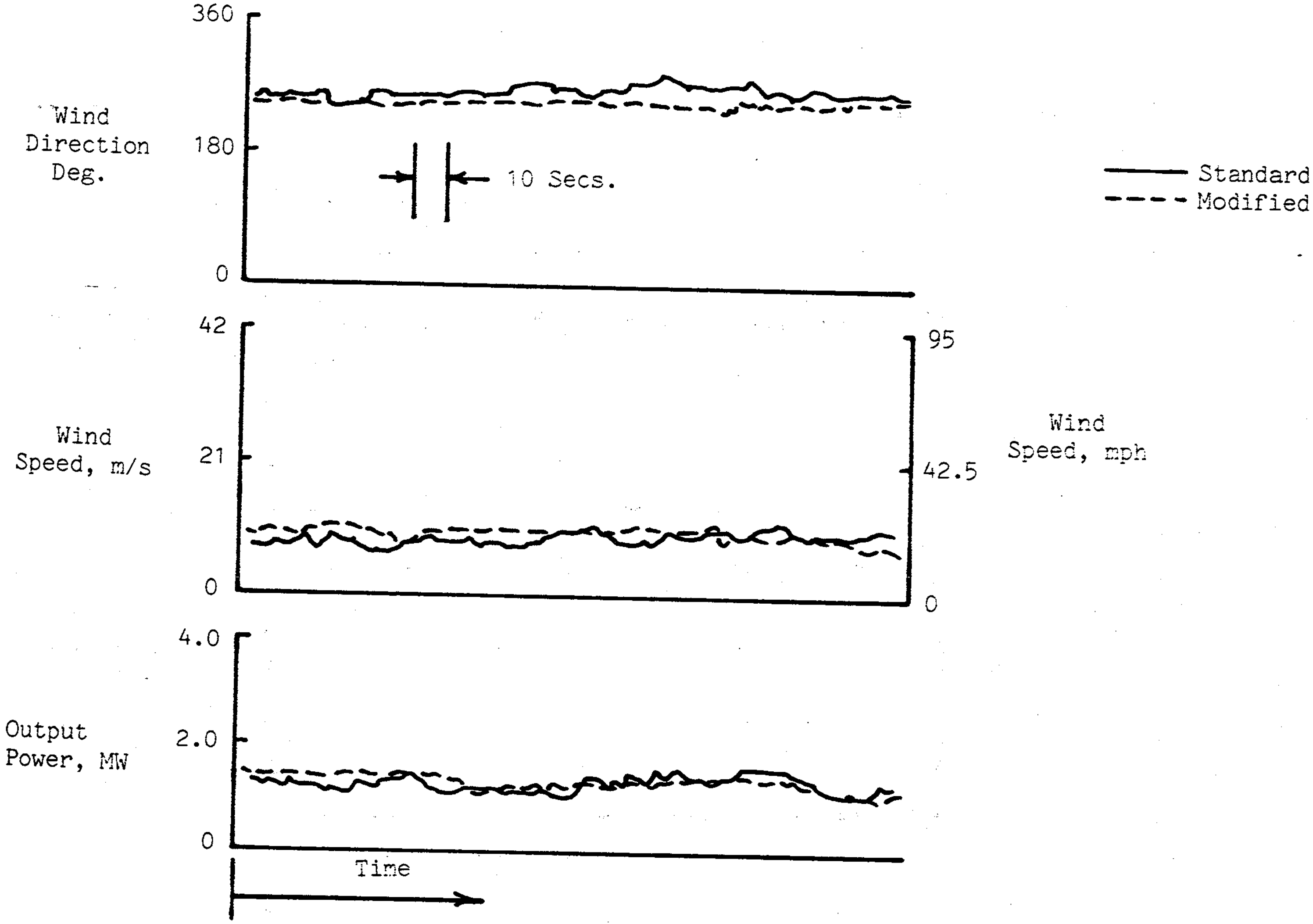
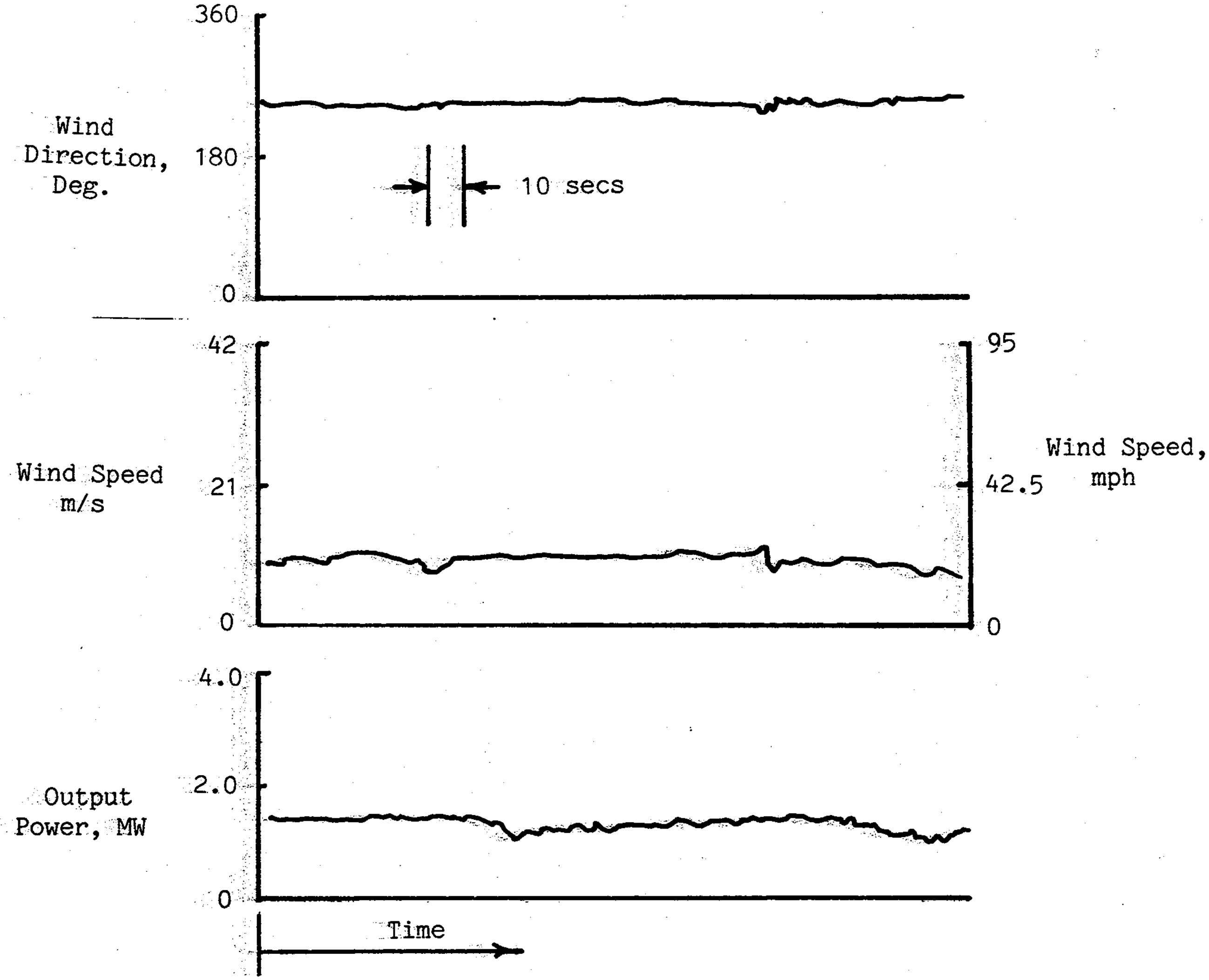


Figure 2. - Photograph of suction side of wind turbine blade showing array of vortex generators. Inset photograph shows individual vortex generator.



(a) V = 7.6 - 10.3 m/s

Figure 3. - Time histories of output power, wind speed and wind direction for the MOD-2 wind turbine generator.



(b) V = 12.5 - 14.3 m/s

Figure 3. - (Concl.)

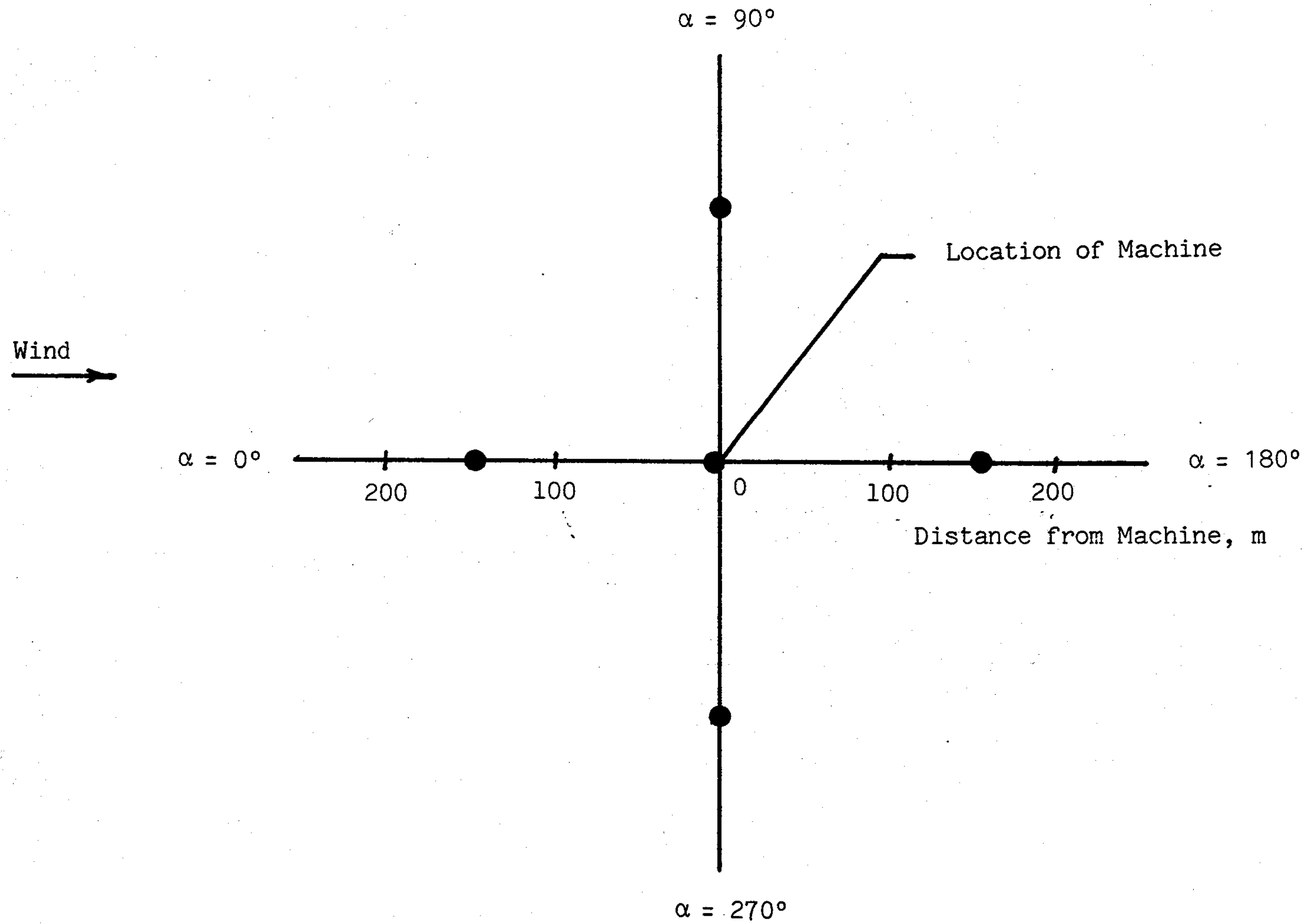


Figure 4. - Plan view sketch showing locations for which acoustic data were measured.

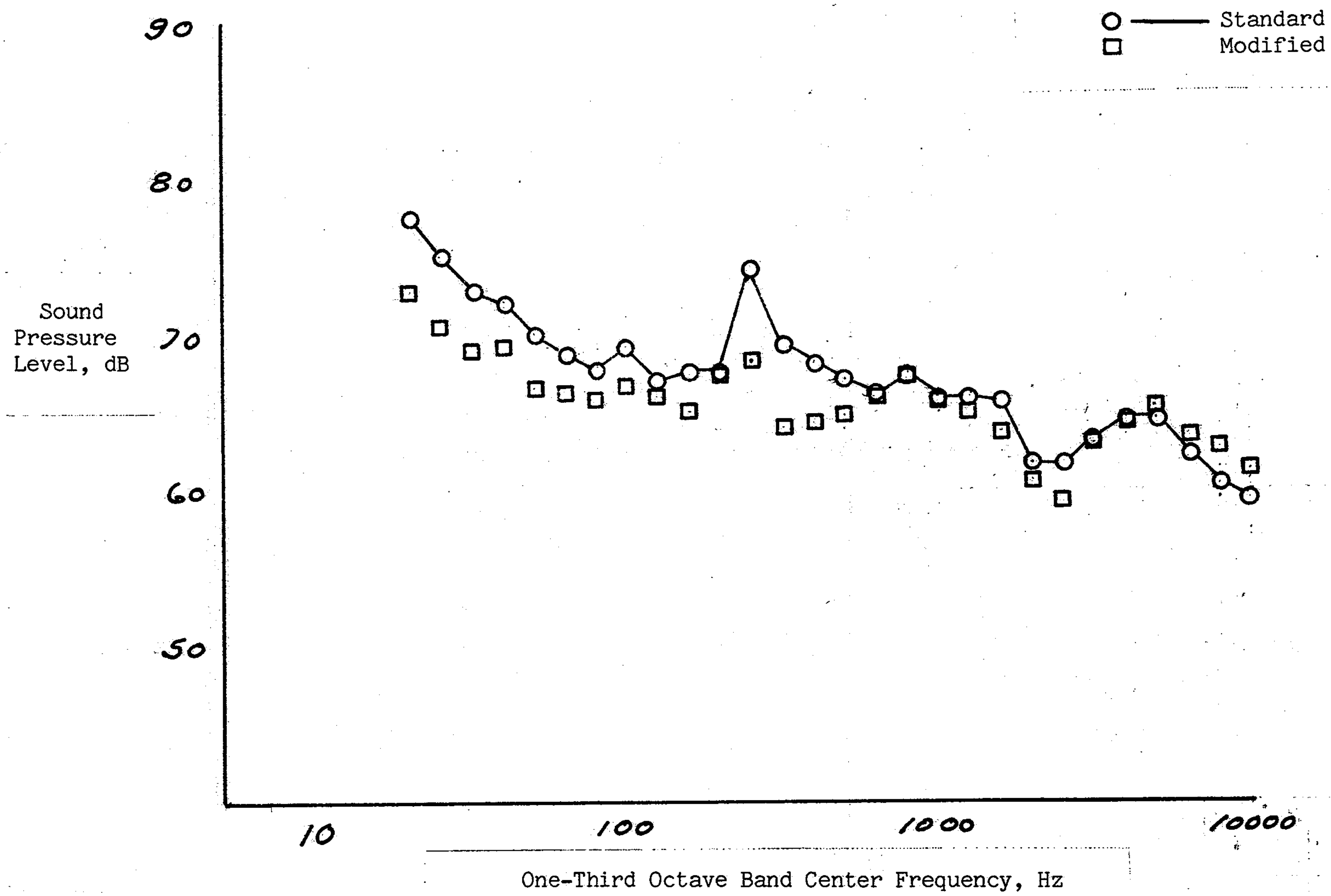


Figure 5. - One-Third Octave Band Spectra of the Near Field Noise from the MOD-2 Wind Turbine Generator. V = 7.6 - 10.3 m/s, P = 1.4 Mw

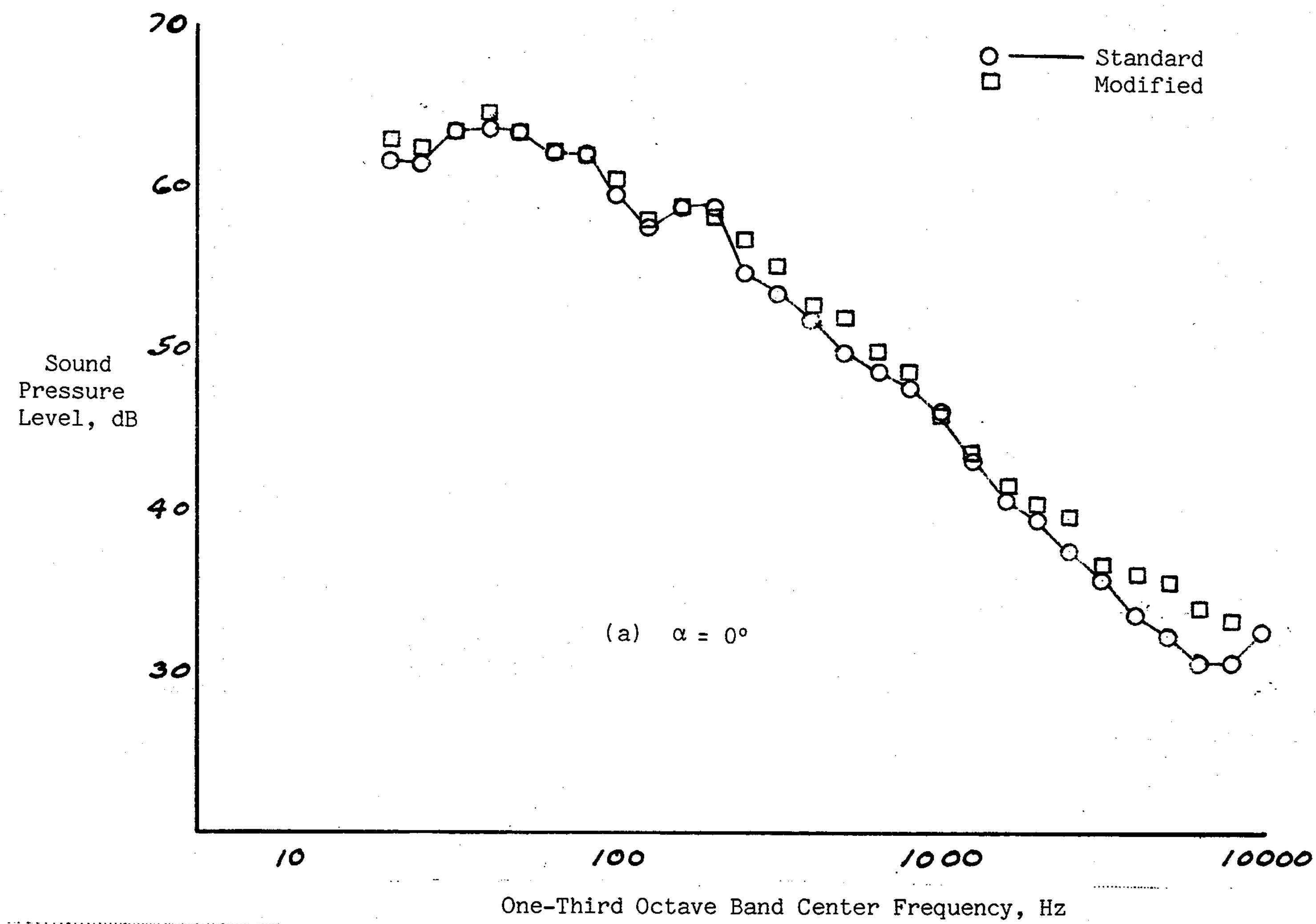


Figure 6. - One-Third Octave Band Spectra of the Far Field Noise from the MOD-2 Wind Turbine Generator at Four Different Measuring Points. $V = 7.6$ - 10.3 m/s, $P = 1.4$ MW, $d = 150$ m

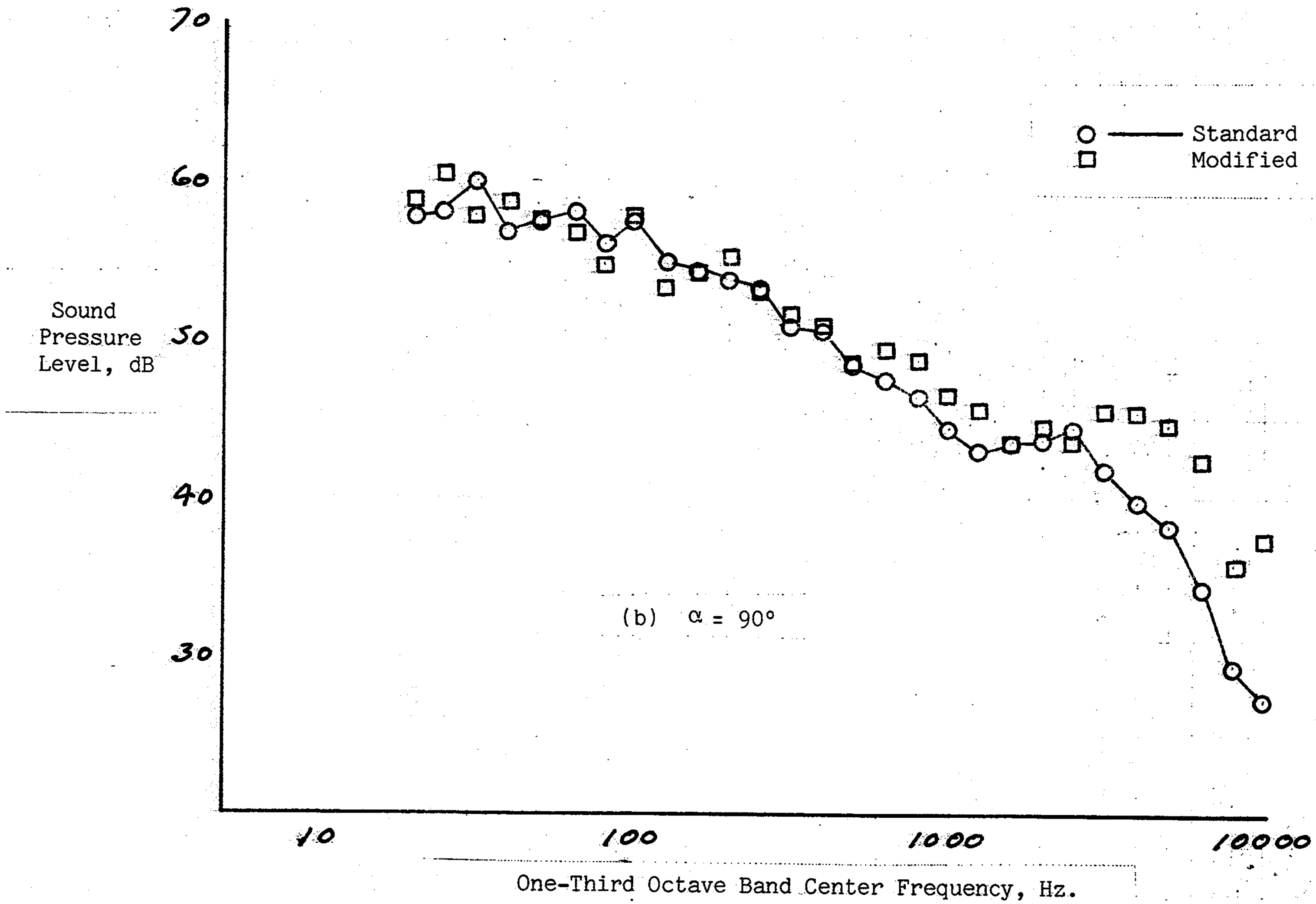


Figure 6. - (Cont.)

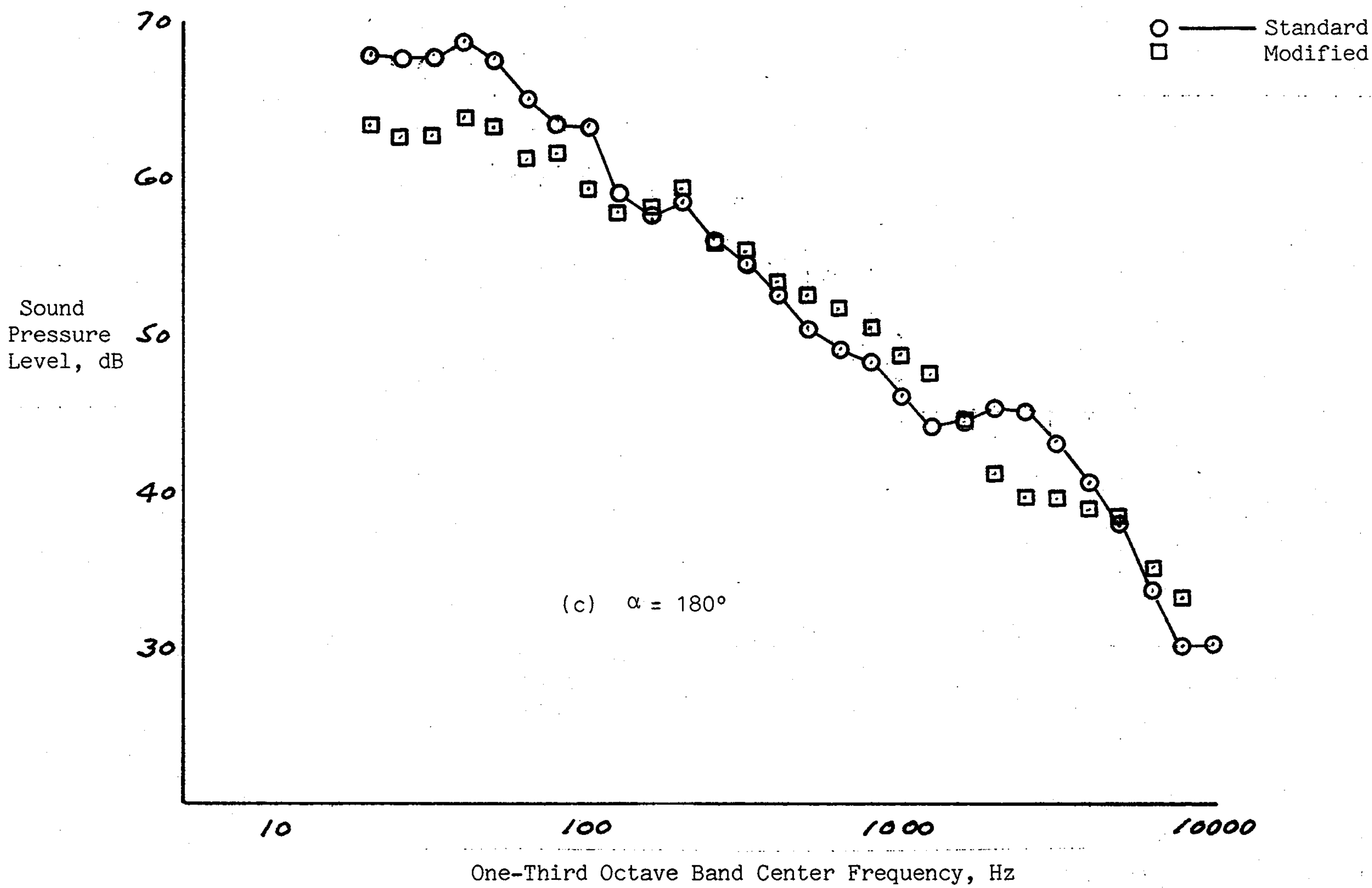


Figure 6. - (Cont.)

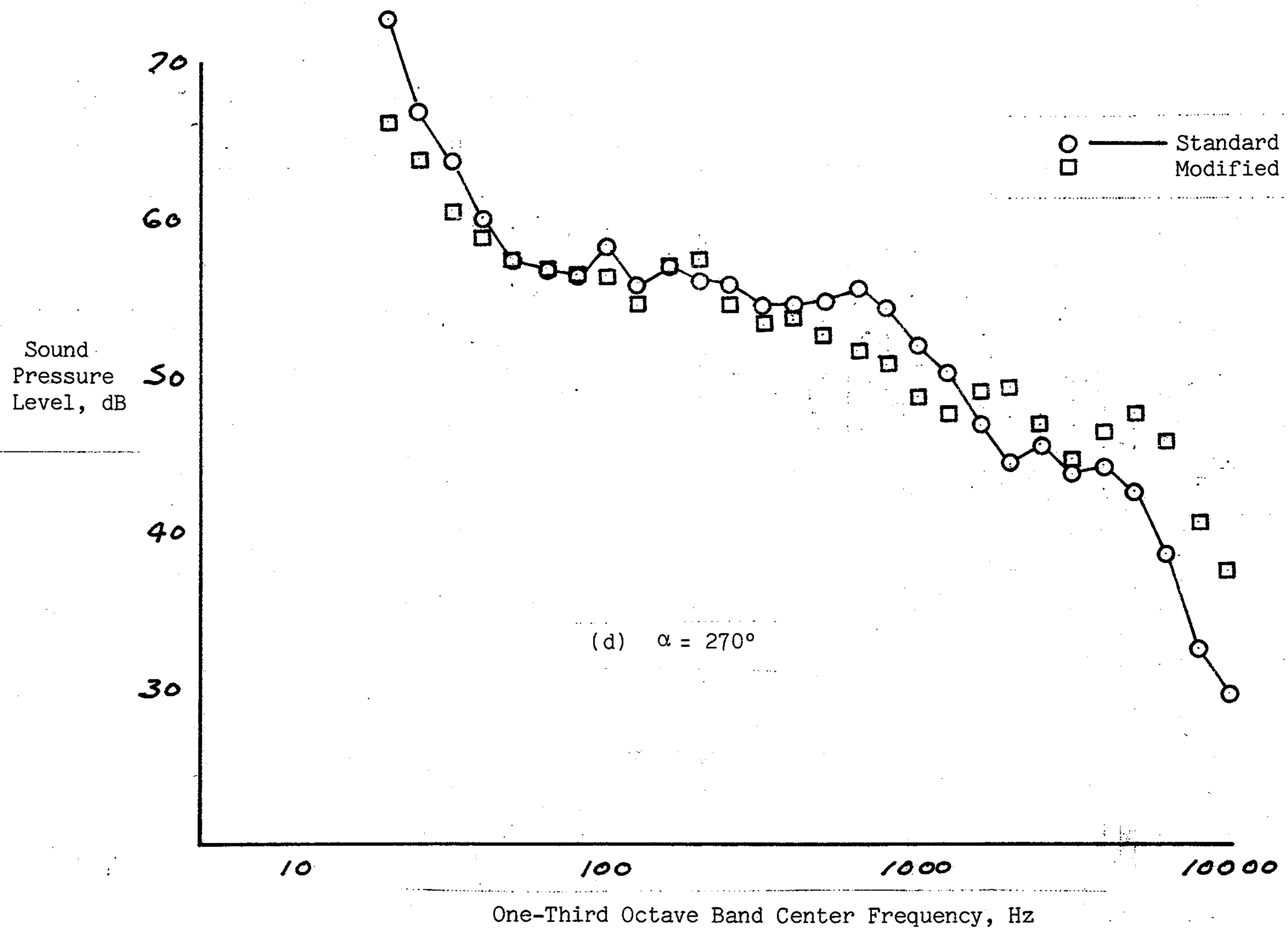


Figure 6. - (Concl.)

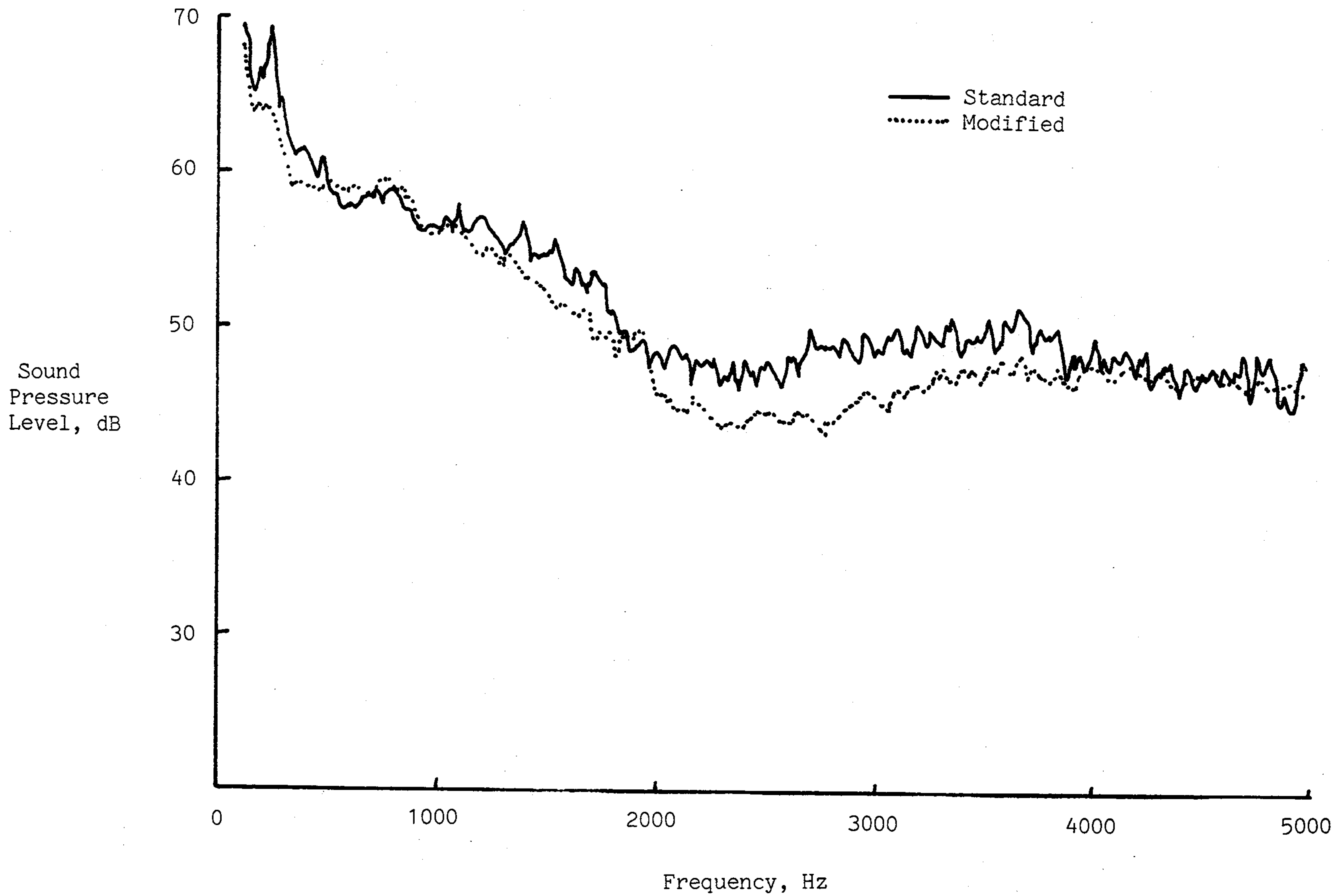


Figure 7. - Narrow Band (Δf = 12.5 Hz) Frequency Analyses of the Near Field Noise from the MOD-2 Wind Turbine Generator. V = 7.6 - 10.3 m/s, P = 1.4 MW

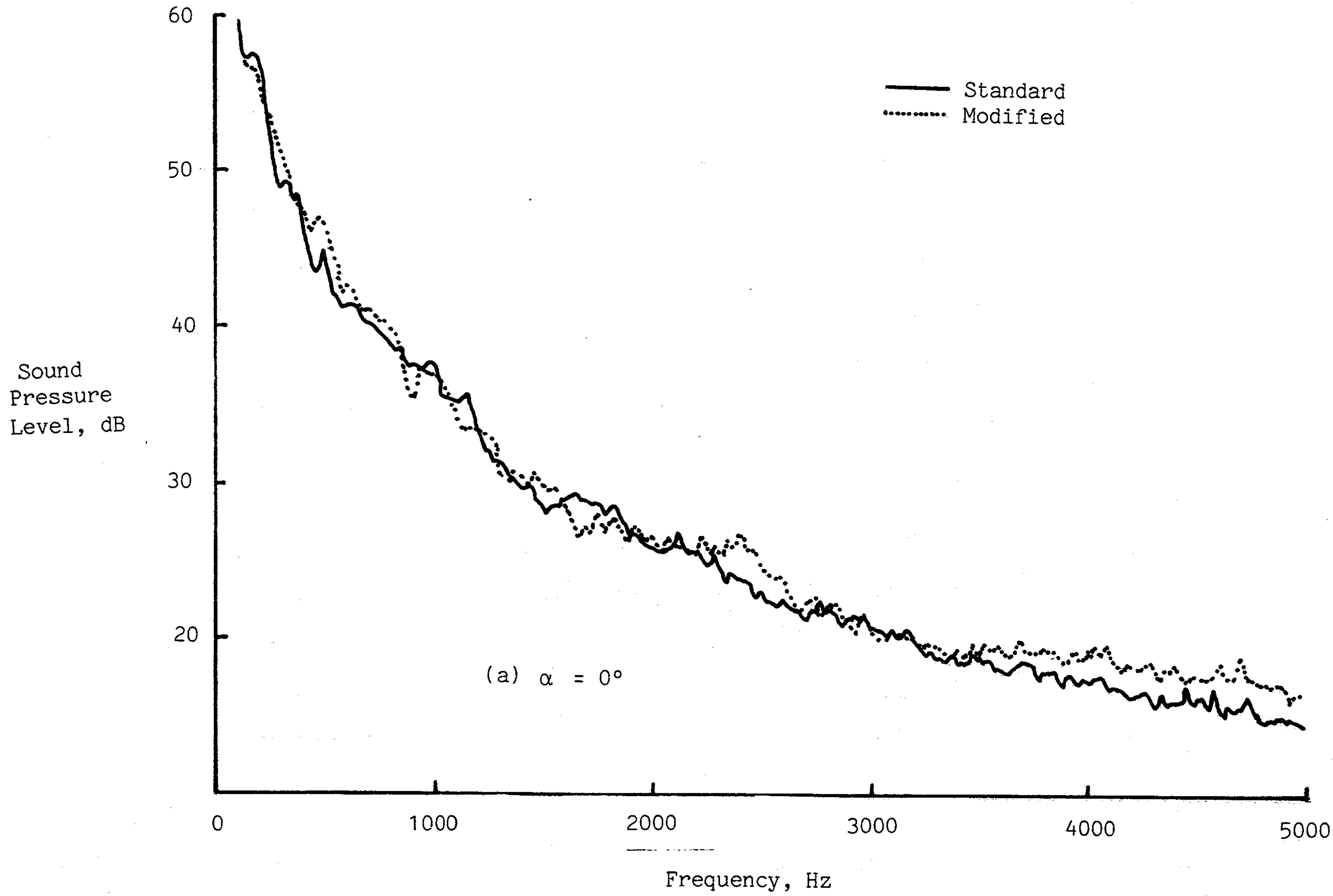


Figure 8. - Narrow Band (Δf = 12.5 Hz) Frequency Analyses of the Far Field Noise from the Mod-2 Wind Turbine Generator at Four Different Measuring Points. V = 7.6 - 10.3 m/s, P = 1.4 MW, d = 150 m

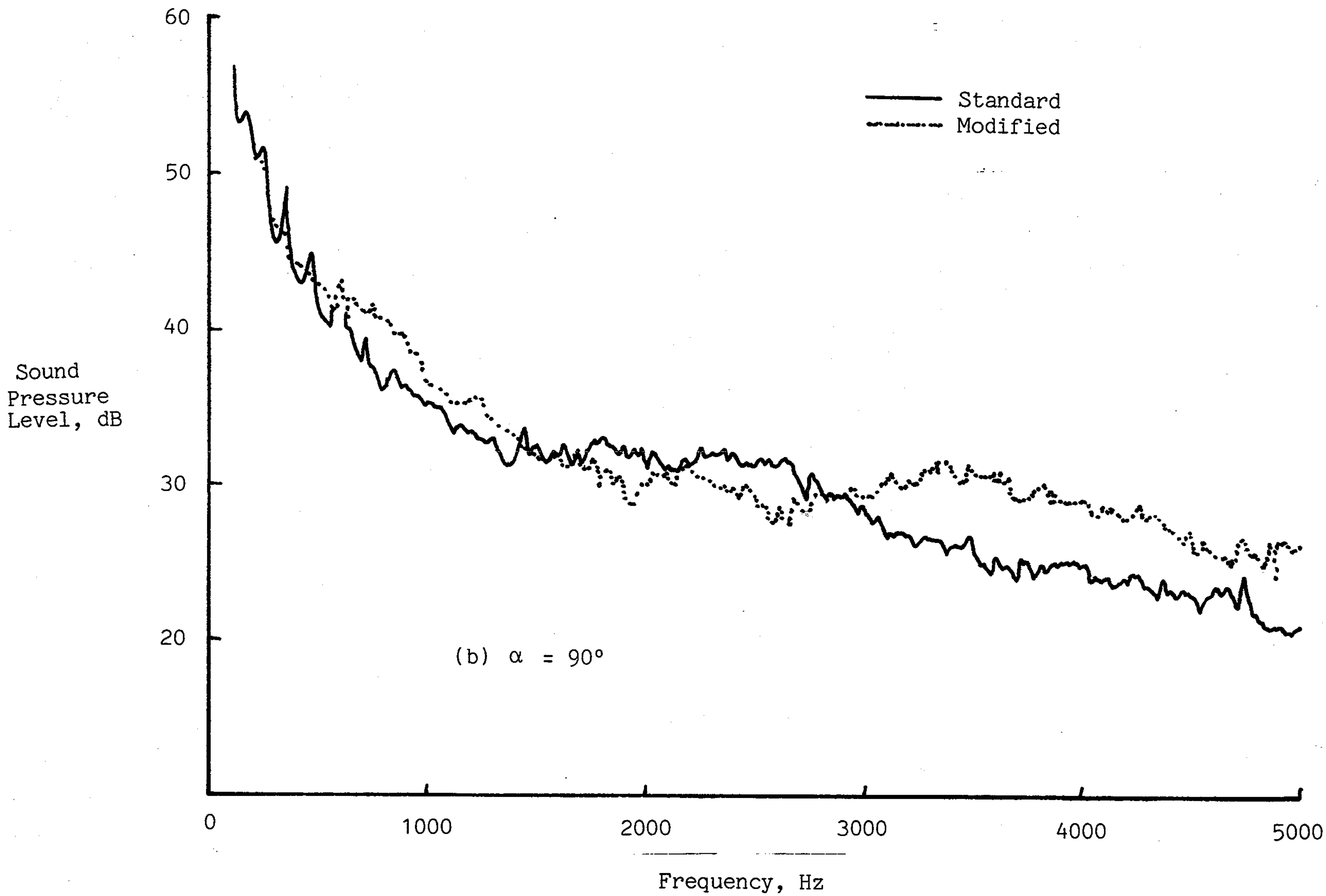


Figure 8. - (cont)

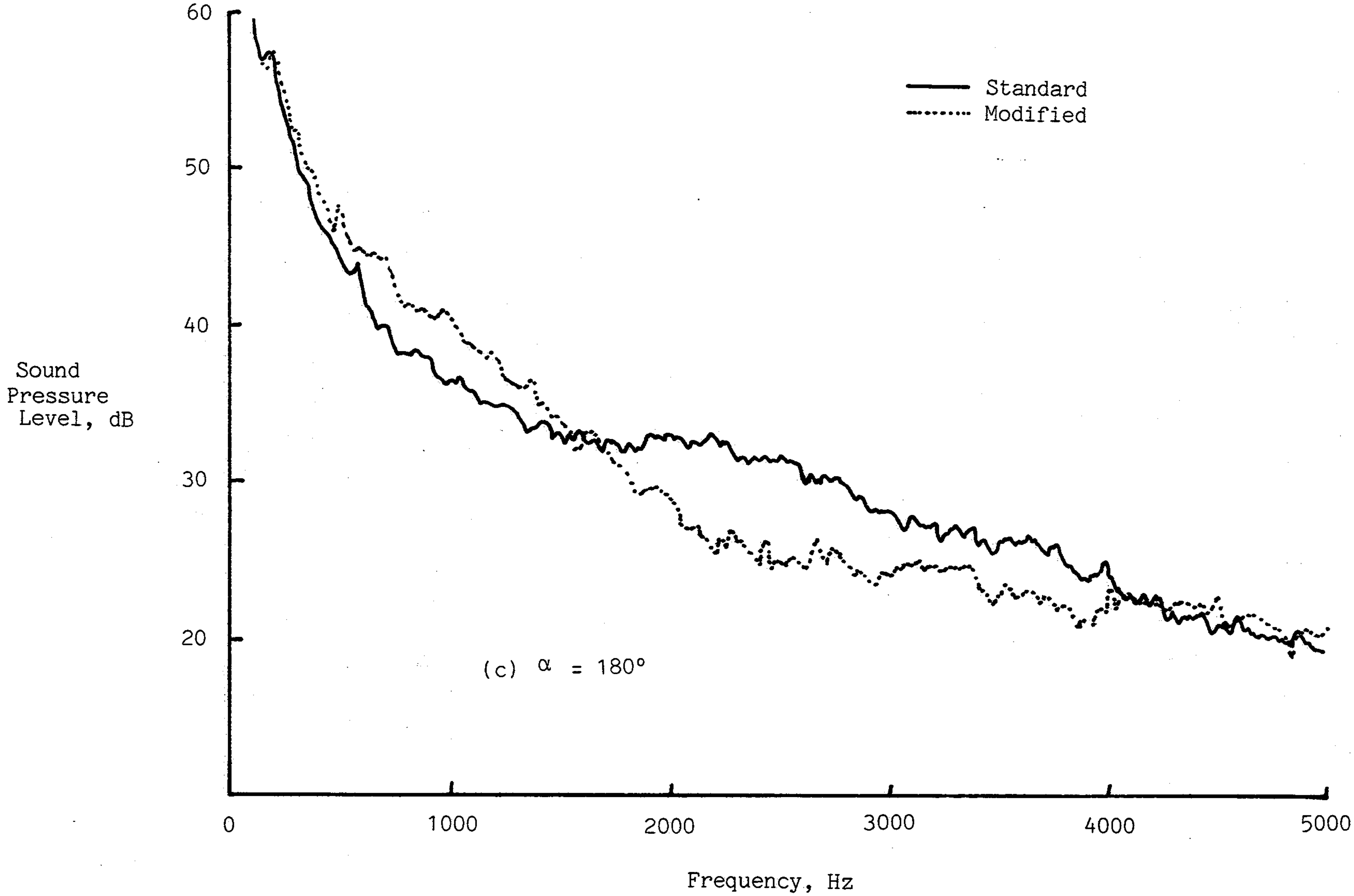


Figure 8. - (cont)

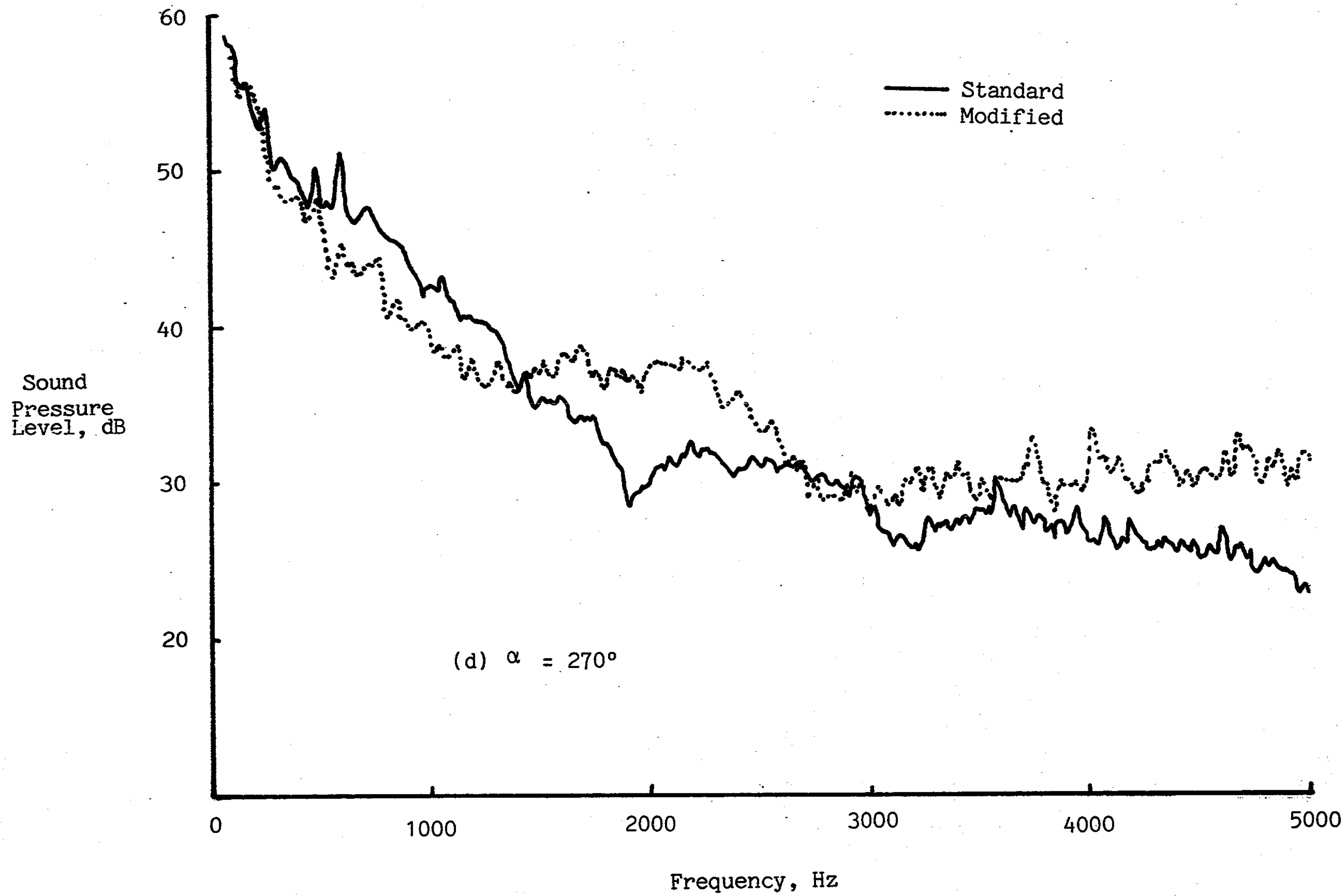


Figure 8. - (Concl.)

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16. Abstract

Comparison noise measurements have been made for a standard MOD-2 machine and for one modified to include an array of vortex generators on the suction sides of the blades near maximum thickness. Data were obtained for comparable azimuth angles and distances for a range of wind velocities of 7.6 - 10.3 m/s and for power outputs of 1.4 MW. Since the observed differences are small it is concluded that the inclusion of vortex generators on this machine will result in no significant increase in environmental impact due to noise.

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