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SOME CALCULATED EFFECTS OF NON-UNIFORM INFLOW ON THE RADIATED NOISE OF A LARGE WIND TURBINE

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INTRODUCTION

The operation of large wind turbines such as the one shown in Figure 1 may become commonplace in the future as an alternate source of energy (refs. 1 and 2). Because of particular constraints regarding their locations and schedules for efficient operation, there is concern for adverse community impact due to noise.

Since the rotor-support tower configuration can in some cases be a dominant factor in noise generation, the current study was performed to evaluate the potential noise problems of configurations in which the rotor is located downwind of the support tower. In such configurations, the tower structure can interfere with the inflow to the rotor and can thus result in a non-uniform circumferential disk loading. In order to evaluate such an effect, application was made of a recently documented computer program for the calculation of noise from advanced propellers (ref. 3). This program which is based on a numerical technique for implementing the theory of reference 4, produces results in both the time and frequency domain and is applicable to noise prediction from large distributed sources such as a propeller disk over which the aerodynamic loading is a variable.

The purpose of this paper is to present the results of noise calculations for which the loading around the circumference of the rotor disk varied in a manner simulating two types of tower wake deficiencies and to compare these results with similar noise calculations for a uniform disk loading case.

APPARATUS AND METHODS

Some of the specifications of the example wind turbine for which calculated noise data are presented are given in Table I. It is a 2000 KW capacity machine which consists of a two-blade 61 meter (200 ft.) diameter rotor mounted on a 42.7 meter (140 ft.) truss type tower. The rotor is mounted so that the inflow first encounters the tower structure, and then enters the rotor disk. The blades are linearly tapered in chord, are twisted along the span, and operate with variable pitch to control the rotor

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speed at 35 rpm. The estimated steady loading patterns along the blade chord and span which were used for all calculations are shown in Figure 2. The circumferential load distributions for the rated turbine output power were approximated in two ways for the cases where the inflow to the rotor disk was interrupted by the support tower wake and are shown in Figure 3, b and c. A uniform circumferential load distribution was assumed for the baseline cases without tower wake (fig. 3a).

Radiated Noise Calculations

Noise calculations for far field conditions around the wind turbine have been made by means of a modified version of the Farassat/Nystrom propeller noise prediction program described in Reference 3. The program properly accounts for the significant geometry features of the rotor, its operating conditions, and the non-uniform distribution of aerodynamic loading over the rotor disk. It is particularly useful for the studies of this paper which were made for the evaluation of the effects of ingestion by the rotor of the tower wake which contains velocity deficiencies.

RESULTS AND DISCUSSION

Calculations were made for field points 1,000 meters distant and for a range of azimuth angles in a plane 300 meters below the hub of the wind turbine (see fig. 4) which is assumed to be located on a hill. Instantaneous acoustic pressure time history, frequency spectra, and directivity information were calculated and are summarized in data Figures 5-7.

Instantaneous Pressure Time Histories

Figure 5 presents the calculated pressure time history at the $\alpha = 0°$ location and for three operating conditions, namely: the case for uniform inflow to the disk for which there is no tower strut interference, and then two cases for different tower strut interference models. The associated pressure time histories for one blade passage for each case are shown. For the uniform inflow case (fig. 5a), the blade passage pulse is minimal and cannot be observed when plotted at this scale. For the single loading notch case (fig. 5b), the calculated signature has negative and positive peaks separated in time by an amount related to the width of the notch. Likewise, the peak amplitudes are related to the depth of the notch. On the other hand, the bottom trace (fig. 5c), resulted from an assumed double notch inflow pattern which would represent the flow around the large corner members of the truss structure. The resulting time history pattern resembles some that have been observed for large wind turbines and there is thus reason to conclude that the bottom loading pattern is representative of the loading in the example installation.

Frequency Spectra

The corresponding frequency spectra calculations are shown in Figure 6. Computations were carried out for the first 50 harmonics of the blade passage frequency and the results are shown for each of the circumferential loading conditions of Figure 3. The most obvious result is that the spectrum for the uniform inflow case (blocked-in circle symbol) contains only a single harmonic of significant amplitude; all others being off scale at the bottom. The notched loading cases on the other hand both produce significantly higher fundamental components and in addition there are many strong harmonics in the frequency range up to at least 60 Hz. This result suggests that a configuration for which the tower interference is minimized would have markedly more favorable noise characteristics. A comparison of the two spectra for the notched loadings reveal no significant differences due to notch details. Thus it may be concluded that the presence of flow deficiencies is a major function in the noise produced, whereas the details of such deficiencies may be of only secondary importance.

Directivity Pattern

In order to define some of the directivity characteristics of the wind turbine noise, a series of calculations were made for the double notched loading condition and over the range of azimuth angles indicated in Figure 4. These far field noise results are shown for comparison in Figure 7. Calculated spectra are presented at three different azimuth angles along with the associated overall noise levels. For the case indicated the overall levels vary from 72.9 dB at the 0° location and 70.2 dB at the 45° location down to 59.7 dB at 90°. The relatively high levels that are indicated down wind and near the axis of rotation result at least in part from the assumed asymmetric loading. A comparison of the associated spectra indicate that the levels of the lowest order harmonics are comparable and that the differences in the overall levels results mainly from differences in the levels of the higher harmonics.

CONCLUDING REMARKS

Computations by the Farassat/Nystrom method indicate that for the uniform inflow case, a large wind turbine generated relatively low noise levels and the first rotational harmonic dominated the spectrum. On the other hand, cases incorporating wake flow deficiencies from the upstream support tower structure indicate substantially increased noise levels for all harmonics; the greatest increases being associated with the higher harmonics.

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3. Nystrom, P. A.; and Farassat, F.: A Numerical Technique for Calculation of the Noise of High Speed Propellers with Advanced Blade Geometry. NASA TP 1662, 1980.
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TABLE I

2000 KW WIND TURBINE SPECIFICATIONS

<u>Rotor</u>	
No of Blades	2
Diameter	61 (200)
Speed, RPM	35
Pitch	variable
Cone angle, Deg	9
Tilt Angle, Deg	0
Location relative to tower	downwind
Direction of Rotation	Counterclockwise (looking upwind)
<u>Blade</u>	
Length, m (ft)	30 (97)
Weight/Blade, Kg (lb)	9800 (21,500)
Airfoil	NACA 44XX
Root Chord, m (ft)	3.7 (12)
Tip Chord, m (ft)	0.85 (2.8)
Chord Taper	Linear
<u>Tower</u>	
Type	Pipe truss
Hub Height Above Ground, m (ft)	43 (140)

Figure 1.- DOE/NASA 2000 KW Experimental Wind Turbine

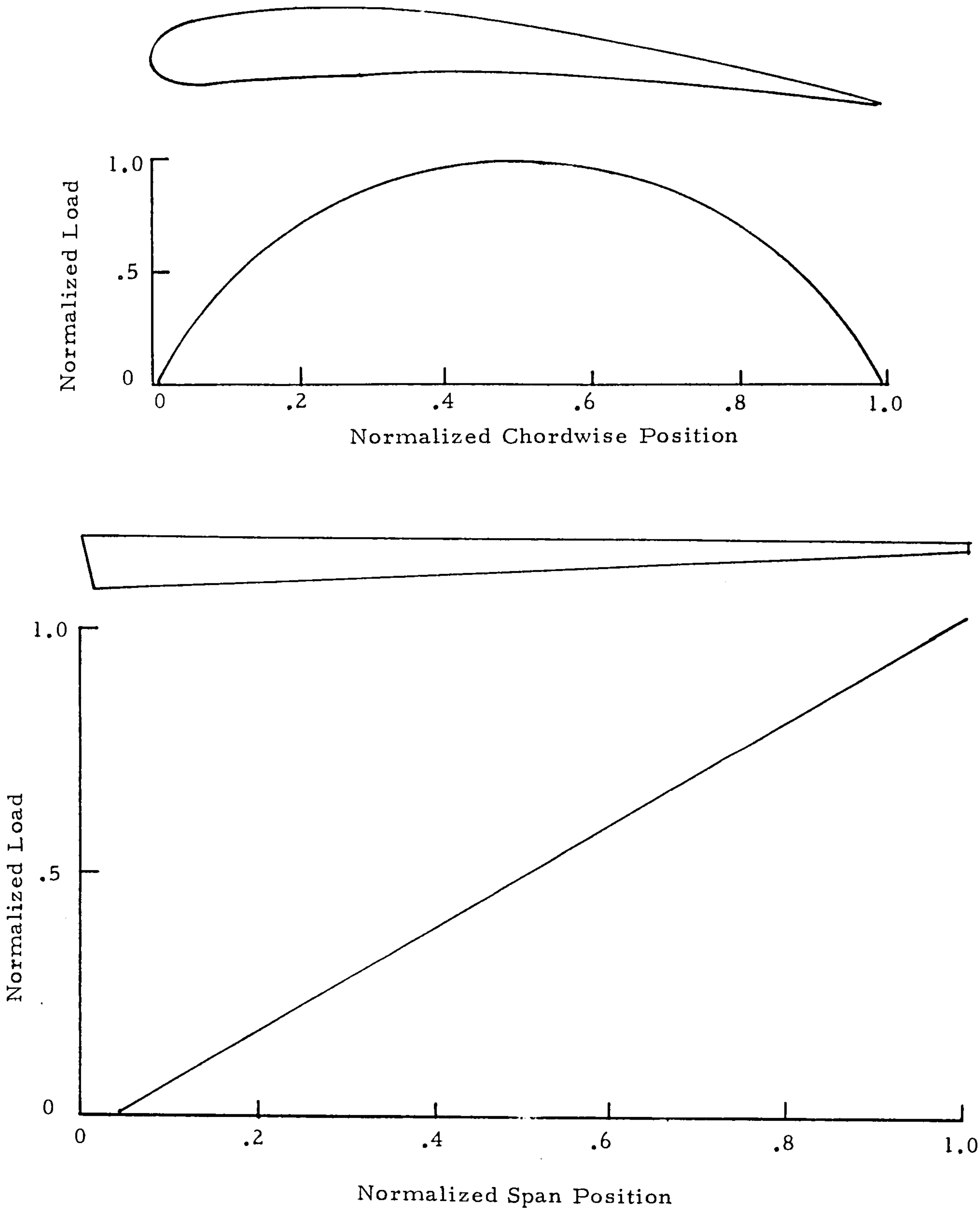
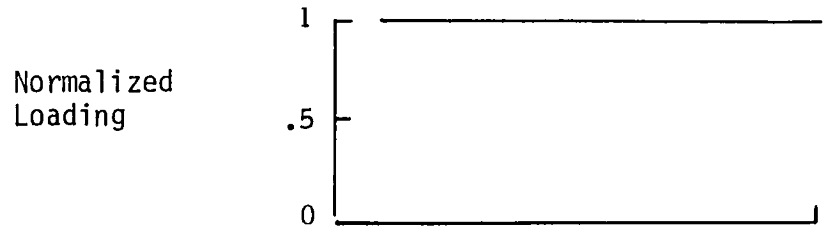
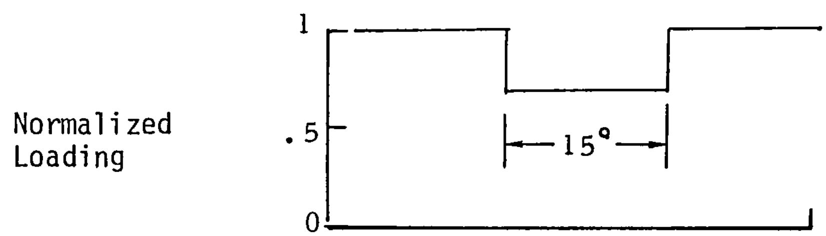


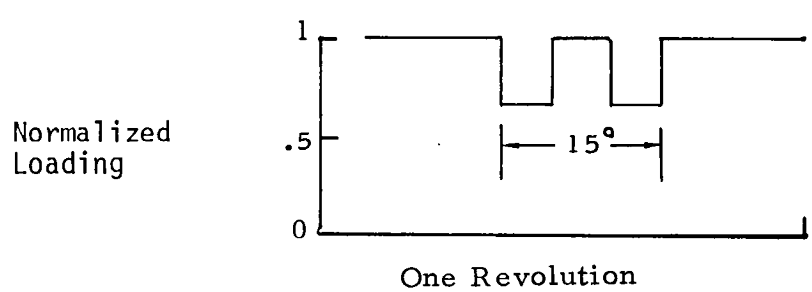
Figure 2.- Assumed Spanwise and Chordwise Aerodynamic Load Distributions for Wind Turbine Rotor Blades



(a) Uniform



(b) Single Notch



(c) Double Notch

Figure 3.- Assumed Circumferential Load Distributions Around the Rotor Disk for Constant Absorbed Power.

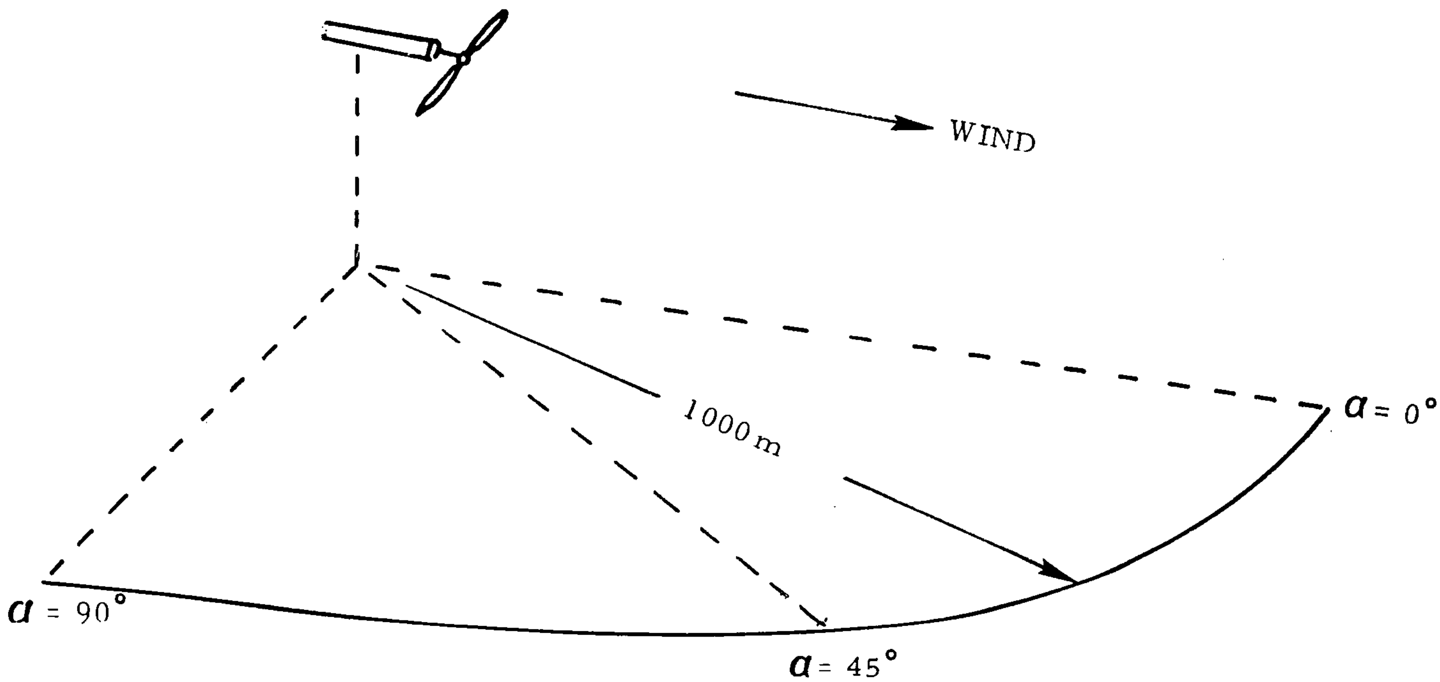


Figure 4.- Coordinate System for Far Field Noise Calculations

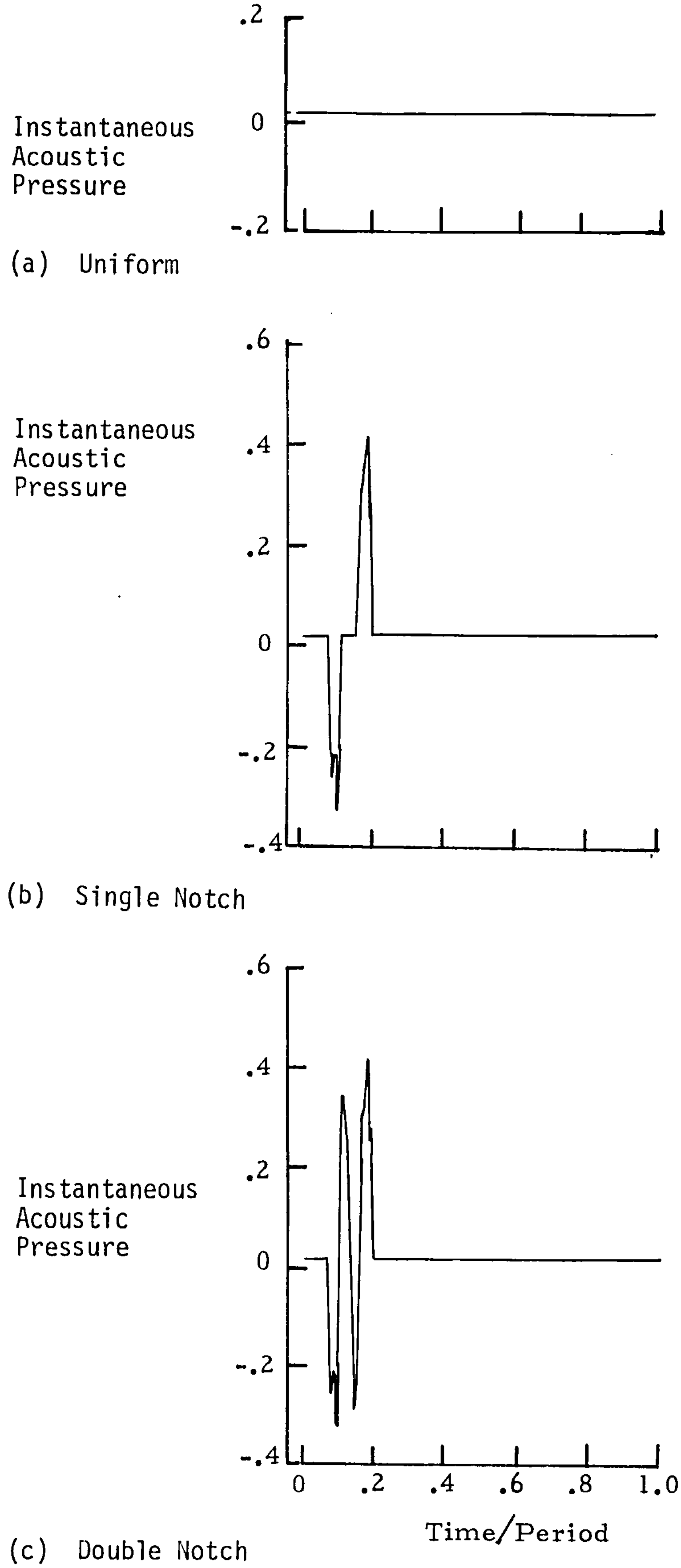


Figure 5.- Calculated Far Field Noise Time Histories For Three Different Blade Loading Patterns. $\alpha = 0°$, Distance = 1,000m

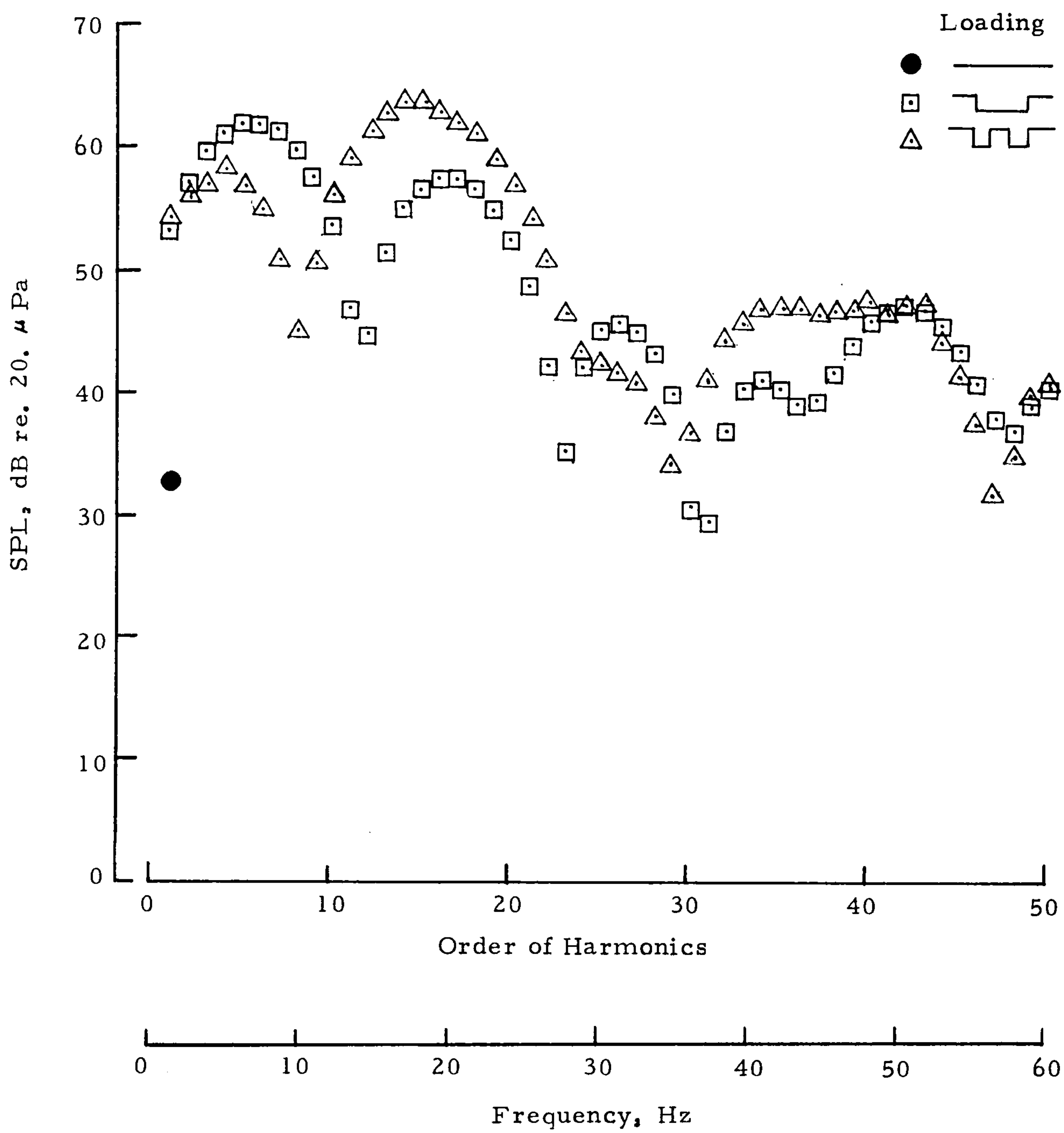


Figure 6.- Calculated Far Field Noise Levels as a Function of Order of the Harmonic for Three Different Loading Patterns, $\alpha = 0°$, Distance = 1,000 m

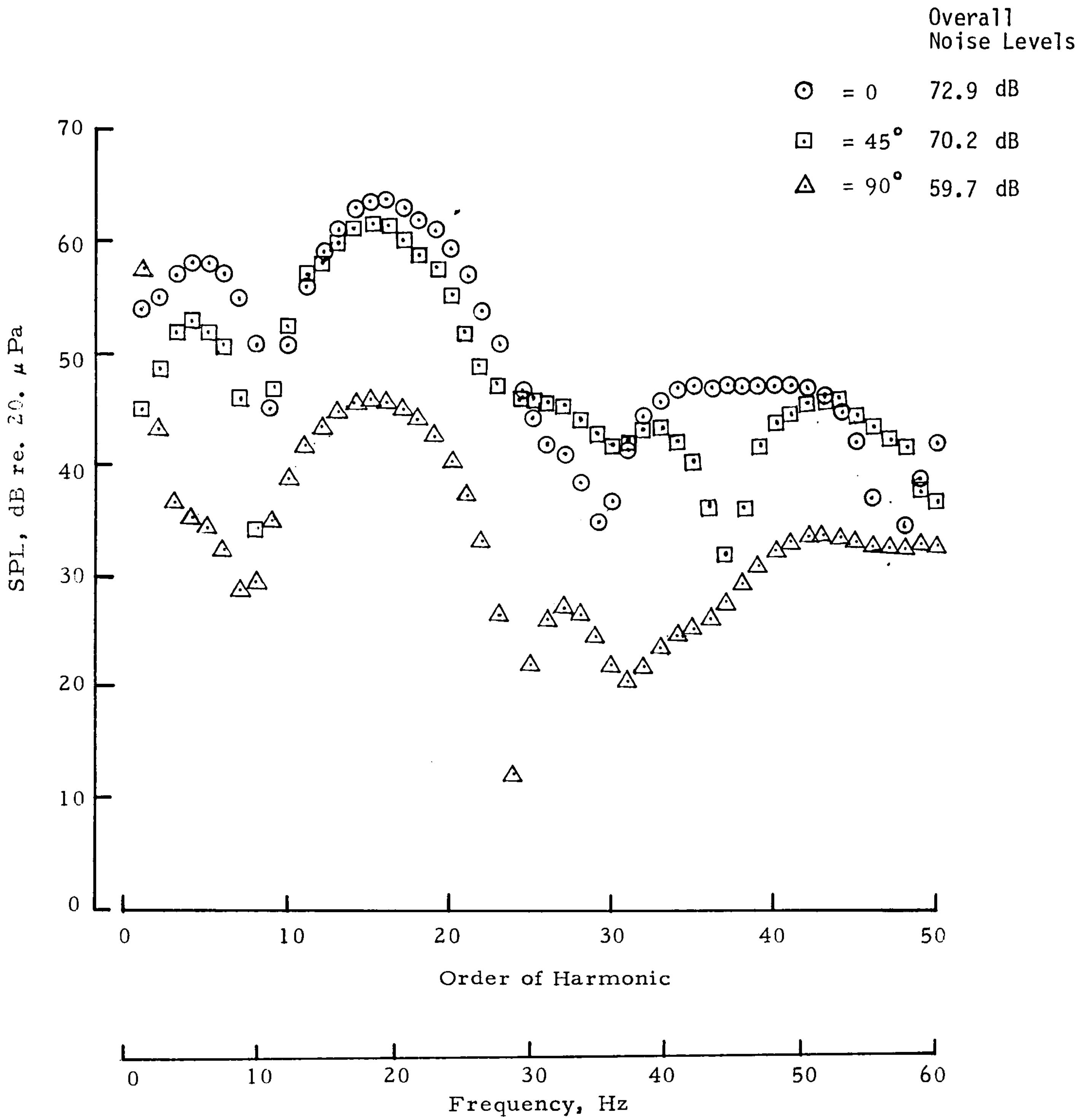


Figure 7.- Calculated Far Field Noise Levels as a Function of Order of the Harmonic for Three Different Azimuth Angles and for a Double Notched Load Distribution. Distance = 1,000m.

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16. Abstract

Far field noise computations have been performed for a large wind turbine to evaluate the effects of non-uniform aerodynamic loading over the rotor disk. A modified version of the Farassat/Nystrom propeller noise prediction program was applied in order to account for the variations in loading due to inflow interruption by the upstream support tower.

The computations indicate that for the uniform inflow case, relatively low noise levels are generated and the first rotational harmonic dominated the spectrum. For cases representing wake flow deficiences due to the tower structure, substantially increased noise levels for all harmonics were indicated, the greatest increases being associated with the higher order harmonics.

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