ROTOR-STATOR INTERACTION NOISE STUDIES OF A SINGLE-STAGE AXIAL-FLOW RESEARCH COMPRESSOR

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ABSTRACT

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This paper gives some experimental results of a noise study of a single-stage axial-flow research compressor. The objective of the study was to investigate the radiation patterns in the far field of the noise due to rotor-stator interactions. The data are presented in the form of radiation patterns and frequency spectra. The radiation patterns compare favorably with results calculated by the method of Tyler and Sofrin. These data show how the radiation patterns are affected by the relative number of rotor blades and stator vanes. Several tests were run to obtain the optimum spacing between the rotor and stator vanes for best results. An appreciable reduction in sound pressure level was observed for the fundamental blade passage frequency and the characteristic radiation lobe amplitudes have been markedly reduced due to increased rotor-stator spacing.

author

INTRODUCTION

The noise from axial-flow compressors is a serious problem with regard to the operation of jet transport aircraft from commercial airports. Because of the limited amount of available information on the generation and propagation aspects of the problem a research program has been initiated at Langley Research Center. The present paper contains some results of one phase of this program which is directed toward evaluation of rotor-stator interaction. Far-field

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noise radiation data from several rotor-stator configurations are presented and are compared where possible with available theory.

APPARATUS AND PROCEDURES

Test Setup

The type of equipment used and the general conditions of the tests are indicated by the photographs of figure 1. The test compressor consisted of a single stage mounted in a suitable airflow duct which was annular in shape and which discharged into a large open area below floor level. Operations were conducted under controlled conditions in an anechoic room. The rotor, a photograph of which is shown in the insert, had 53 blades with root diameter of 10.72 inches and tip diameter of 14.75 inches. The rotor blades were taken from one stage of a multiple-stage compressor of a jet engine. The rotor hub was designed such that the blades were set at the proper pitch angle to obtain efficient aerodynamic operation as a single-stage compressor.

A profile view sketch of the test compressor setup is shown in figure 2. It was driven by a 52-hp variable-speed electric motor at speeds up to 8700 revolutions per minute, which corresponds to a tip speed of 560 feet per second. The microphone for measuring acoustic data was mounted in such a way that it could be moved continuously within inlet center-line level and one quandrant of a 12-foot-radius azimuth circle. All data were recorded on magnetic tape for later playback and analysis. Airflow measurements were made with an array of pitot static tubes located forward of the stator as indicated in the sketch.

Aerodynamic Performance Data

A comparison of measured and calculated radial velocity distribution is given for a high-powered condition in figure 3. Velocity in feet per second is plotted as a function of distance across the air passage in percent of rotor-tip radius. The calculated curve is based on a knowledge of the airfoil-section characteristics along the blade. It can be seen that an approximately uniform velocity profile existed across the duct and that good agreement was obtained between the measured and calculated values. Although not shown on the figure, similar good agreement was also obtained for the lower power conditions.

Range Variables

Because of the flexibility of the compressor test equipment there was an opportunity to investigate ranges of the different variables listed in figure 4. For a fixed rotor configuration tests were performed with stators having 31, 53, and 62 vanes as well as for the no-stator condition. Rotor speed was varied from about 3700 to 8700 rpm. Provisions were made for changing the spacing distance between the rotor and stator from a minimum of 0.53 chord lengths to a maximum of 9 chord lengths. Although no loading effect will be discussed, it should be noted that the loading of the stage could be changed by changing the angle of attack of the stator vanes.

RESULTS AND DISCUSSION

Overall Noise Levels

The data of figure 5 illustrate the type of radiation patterns measured for three different stator configurations. Included are overall noise levels as a function of azimuth angle for 53-vane and 62-vane stators along with comparable data for the no-stator condition. In general, the lowest noise levels were associated with the no-stator case. The radiation pattern for the 53-vane case was characterized by a relative high level in the direction of the axis in front of the inlet. This latter result is in general agreement with observations of references 1 and 2 for the case where the number of rotor blades is equal to the number of stator vanes.

Frequency Spectra

It is significant to study the frequency spectra of the radiated noise. Sample one-third octave band spectra for two different speed conditions for the 53-vane stator configuration are shown in figure 6. The spectra are noted to have a characteristic shape. At the lower rpm condition, represented by the dashed curve, the highest peak in the spectrum is associated with the rotor blade passage frequency (discrete tone). Other lower amplitude peaks at higher frequencies are associated with the appropriate higher harmonics. As speed is increased the peak corresponding to the blade passage frequency moves to higher frequencies as indicated by the solid curve. The increases in noise levels associated with the speed increase are of the same order of magnitude for the discrete tones as for the lower frequency random noise components of the spectrum. In the last two figures of the paper the levels of the one-third octave band centered about the rotor blade passage frequency are plotted in the form of radiation patterns.

Comparison of Calculated and Measured Radiation Patterns

In figure 7 are plotted comparable measured and calculated radiation patterns for the 62-vane stator configuration. One-third octave band levels are plotted relative to the maximum measured value as a function of azimuth angle. A large number of data points were measured in an attempt to define the details of the radiation pattern. The method of reference 1 by which the calculations were made gives only qualitative and not quantitative results. Thus for the purposes of the figure the maximum calculated value is arbitrarily matched to the maximum measured value. The calculations seem to indicate roughly the direction of maximum radiation and the number of lobes in the patterns. They do not, however, predict the detailed lobe structure of the pattern nor do they predict radiation in the direction of axis of rotation.

Effect of Rotor-Stator Spacings

Some experiments have been performed to determine the manner in which the geometry of the rotor-stator combination would affect the shapes of the radiation patterns and the absolute levels of the radiated noise. One of the variables studied was the spacing between the rotor and stator. Some results of this study are presented in figure 8. Plotted in the figure are data for a 53-blade rotor and 62-vane stator for spacings of 0.53 and 6.25 chord lengths. Also shown in the figure are measured data for the same rotor but for the stator completely removed for comparison. It can be seen that the 6.25 chord lengths spacing between the rotor and stator results in a general reduction in noise levels and essentially eliminates the individual lobes of the radiation pattern in the azimuth angle range of 35° to 90°. It should be pointed out that the compressor speed for the two configurations using stator vanes was 8150 rpm as compared to 7875 rpm for the no-stator vane configuration. About one-half of the difference in noise level for the 6.25 chord length spacing and the no-stator configuration in the 0° to 15° azimuth range can be accounted for by this difference in rpm. It may also be mentioned that flow measurements showed aerodynamic efficiencies were comparable for these configurations.

A further increase in spacing to 9 chord lengths (not shown in the figure) eliminated the lobe which peaks at about the 25° azimuth angle, but indicated no further decrease in the noise level for the azimuth angle range of 35° to 90°; nor was there any further decrease in noise level in the 0° to 15° azimuth range.

From the above result it is believed that the amount of noise reduction attainable by increased spacings between the rotor and stator is related to the type of radiation pattern and thus may very well be different for each rotor-stator configuration.

CONCLUDING REMARKS

Discrete frequency and random noise components from a one-stage laboratory compressor, both increased in level with rotor speed and at about the same rate. The discrete frequency radiation patterns for a given rotor were found to vary as the configuration of the stator varies. Increased spacings between rotor and stator resulted in decreased noise levels and in the elimination of most of the individual lobes in the radiation patterns.

REFERENCES

1. Tyler, J. M., and Sofrin, T. G.: Axial-Flow Compressor Noise Studies. SAE Aeronautic Meeting, 1961, Preprint No. 345 D.
2. Bragg, S. L., and Bridges, R.: Noise From Turbojet Compressors. Journal of Royal Aeronautical Society, Vol. 68, No. 637, January 1964.

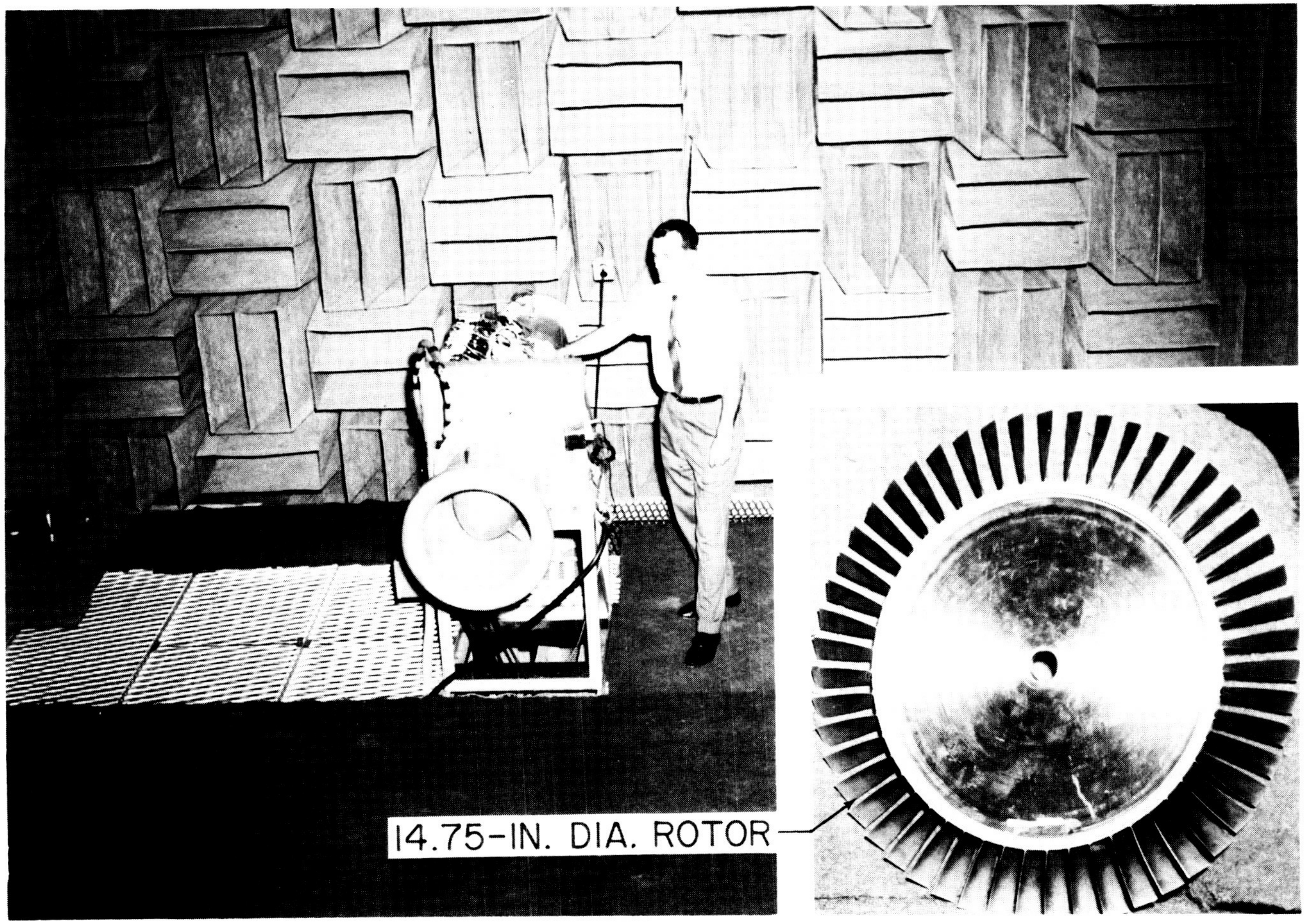

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Figure 1.- Photograph of test setup in test chamber.

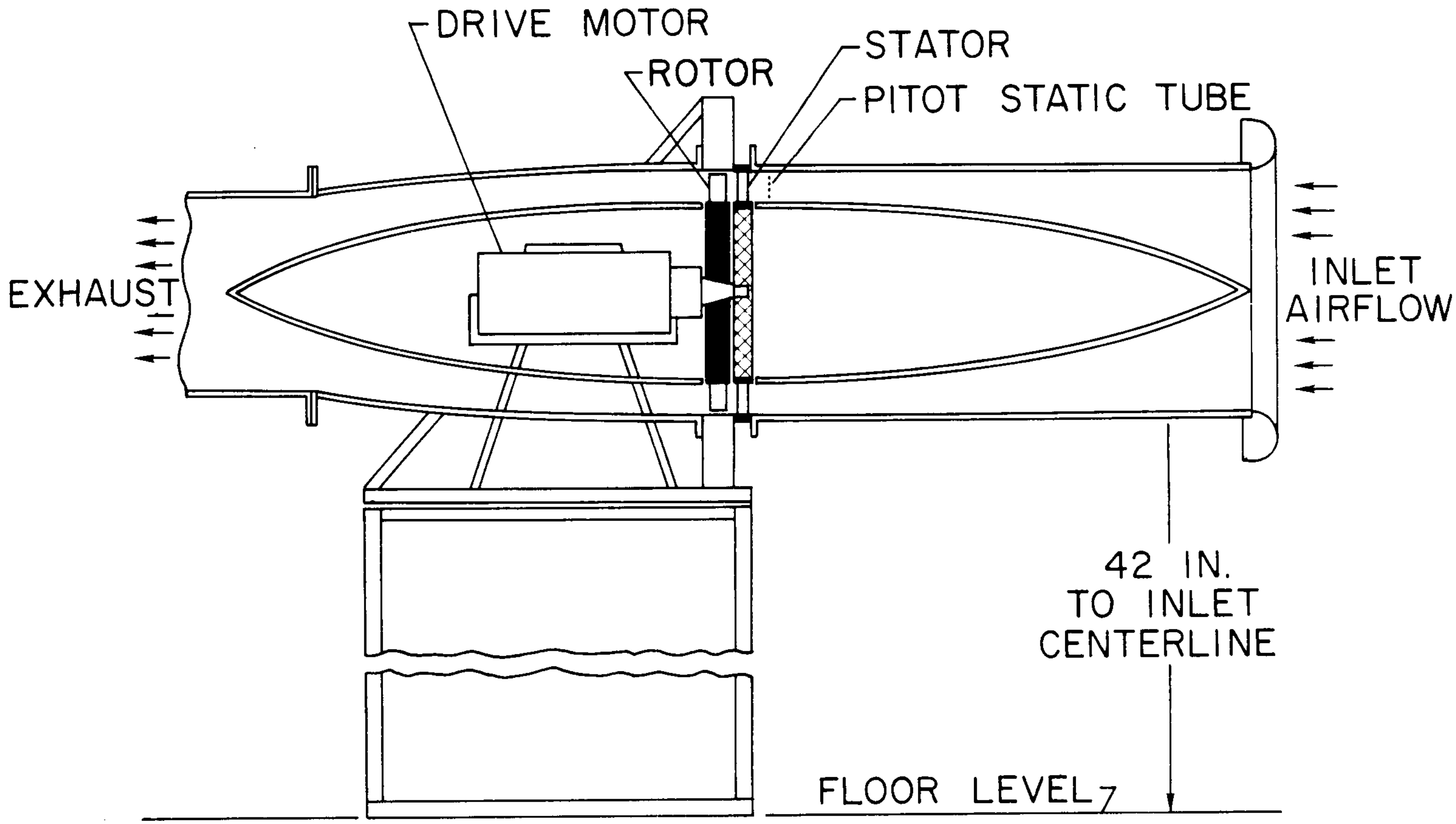

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Figure 2.- Schematic diagram of test setup.

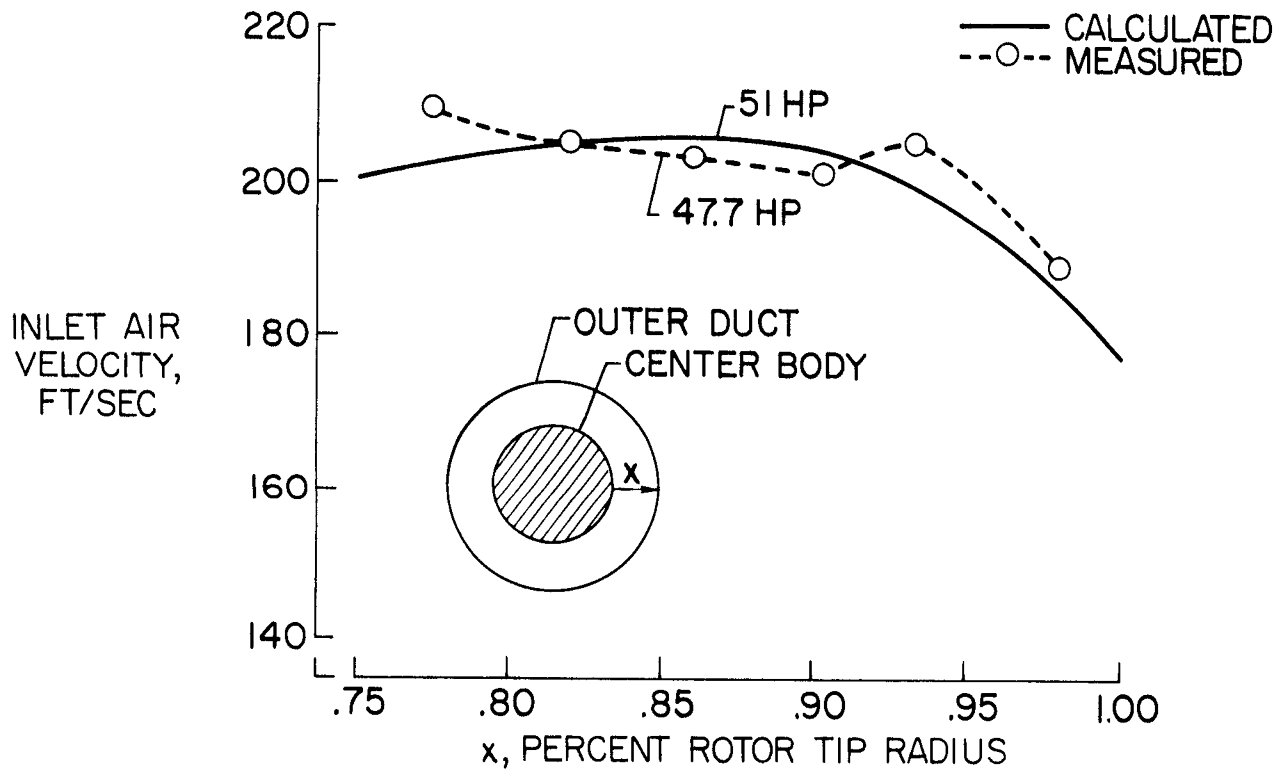

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Figure 3.- Radial velocity distribution in inlet duct.

- NUMBER OF STATOR VANES
- RANGE OF ROTOR SPEED
- ROTOR-STATOR AXIAL SPACING

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Figure 4.- Variables investigated.

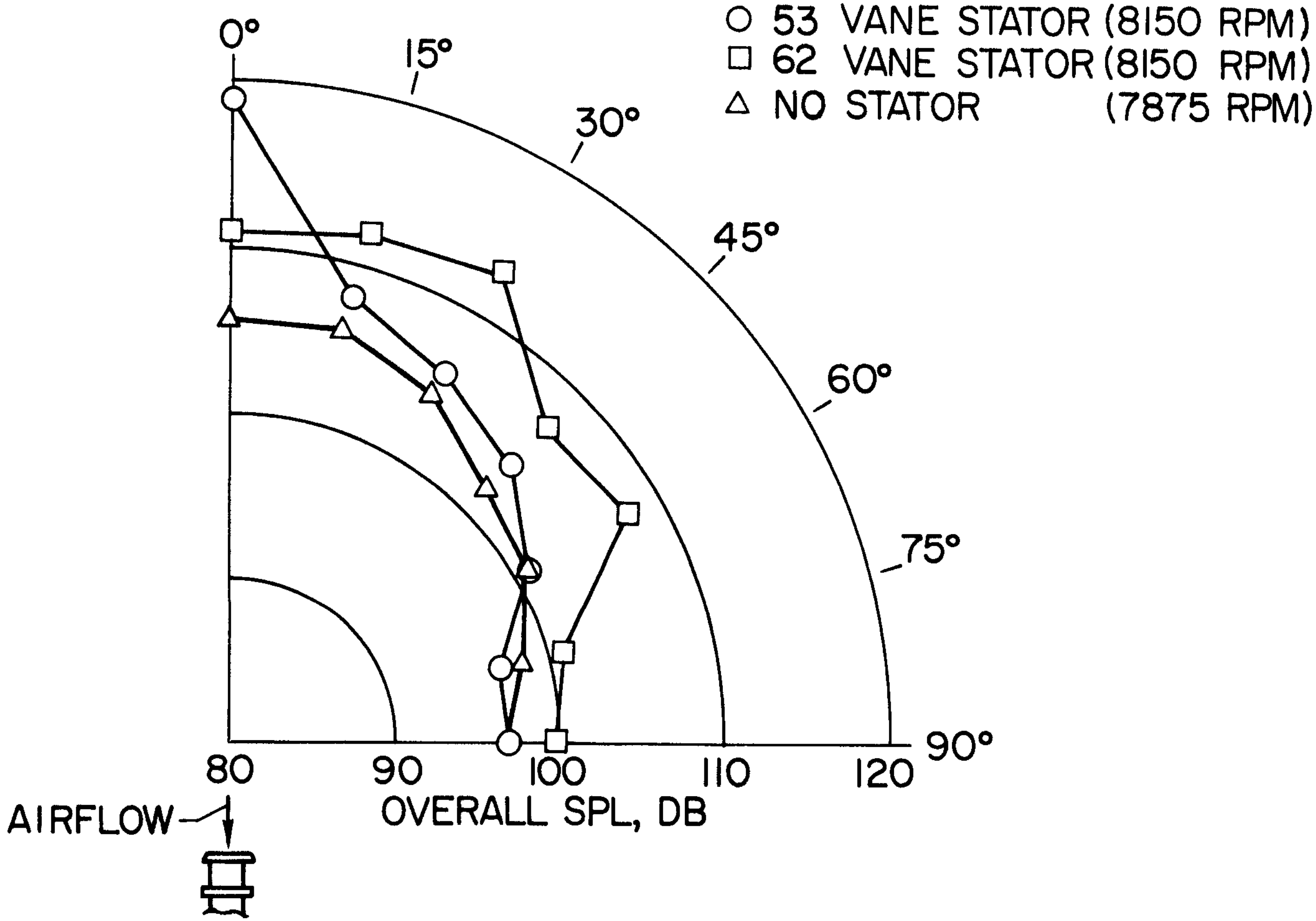

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Figure 5.- Overall-noise radiation patterns for three different test configurations. Measured on 12-foot radius.

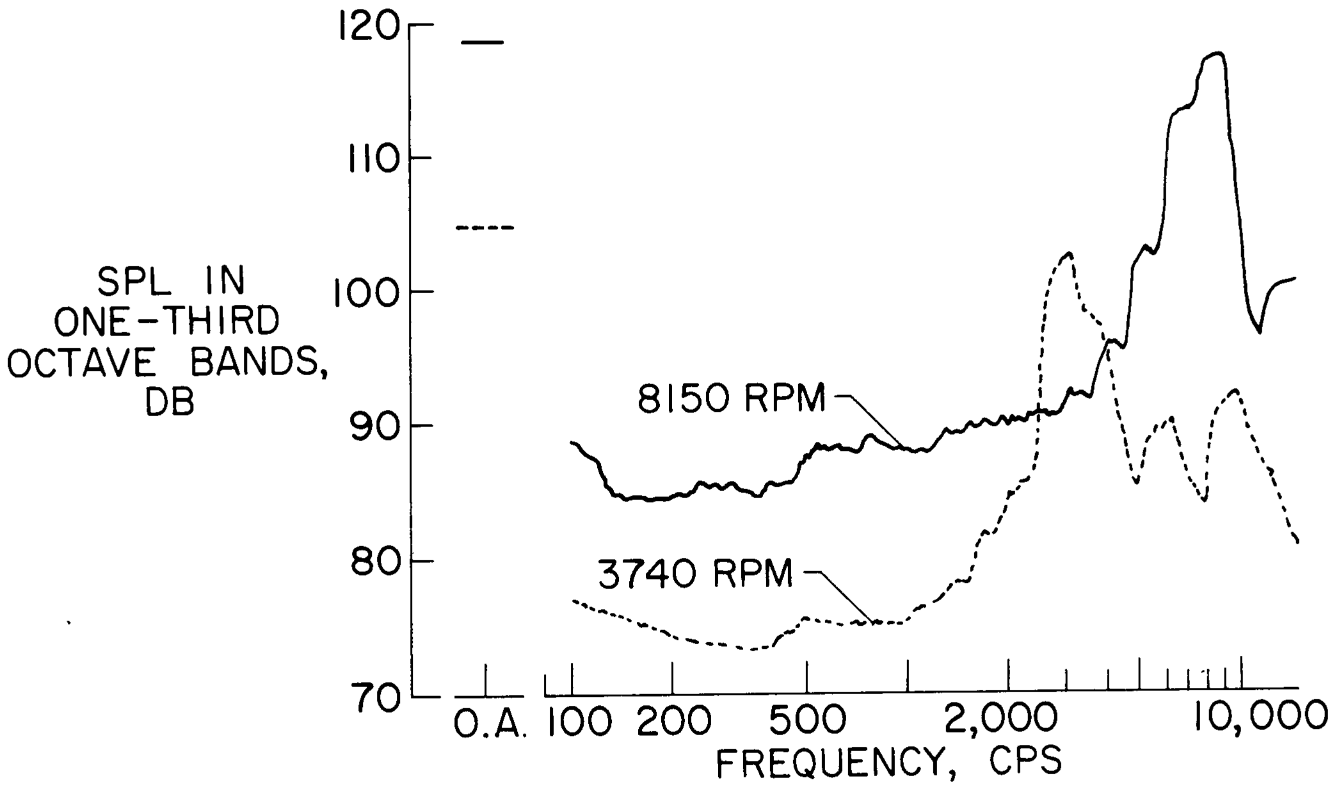

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Figure 6.- One-third octave band spectra for 53 vane stator configuration for two different speed conditions.

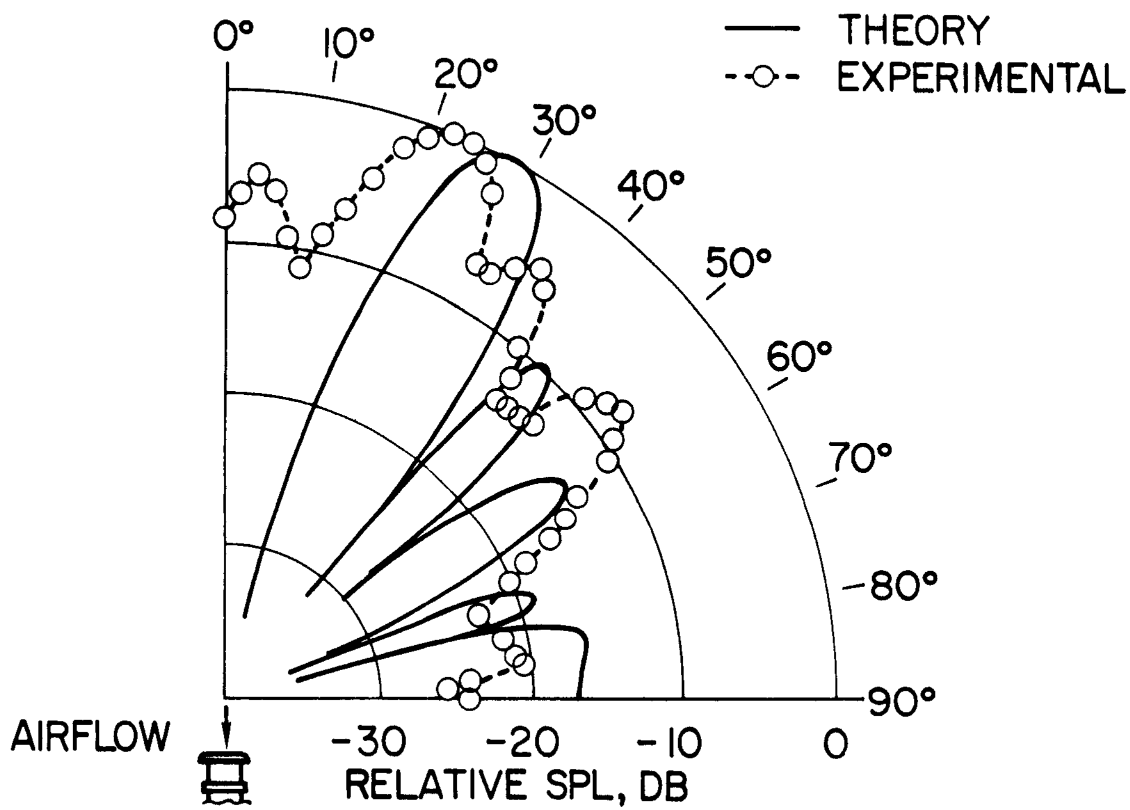

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Figure 7.- Comparison of calculated and measured one-third octave band radiation patterns for 62 vane stator configuration; 0.53 chord length rotor-stator spacing.

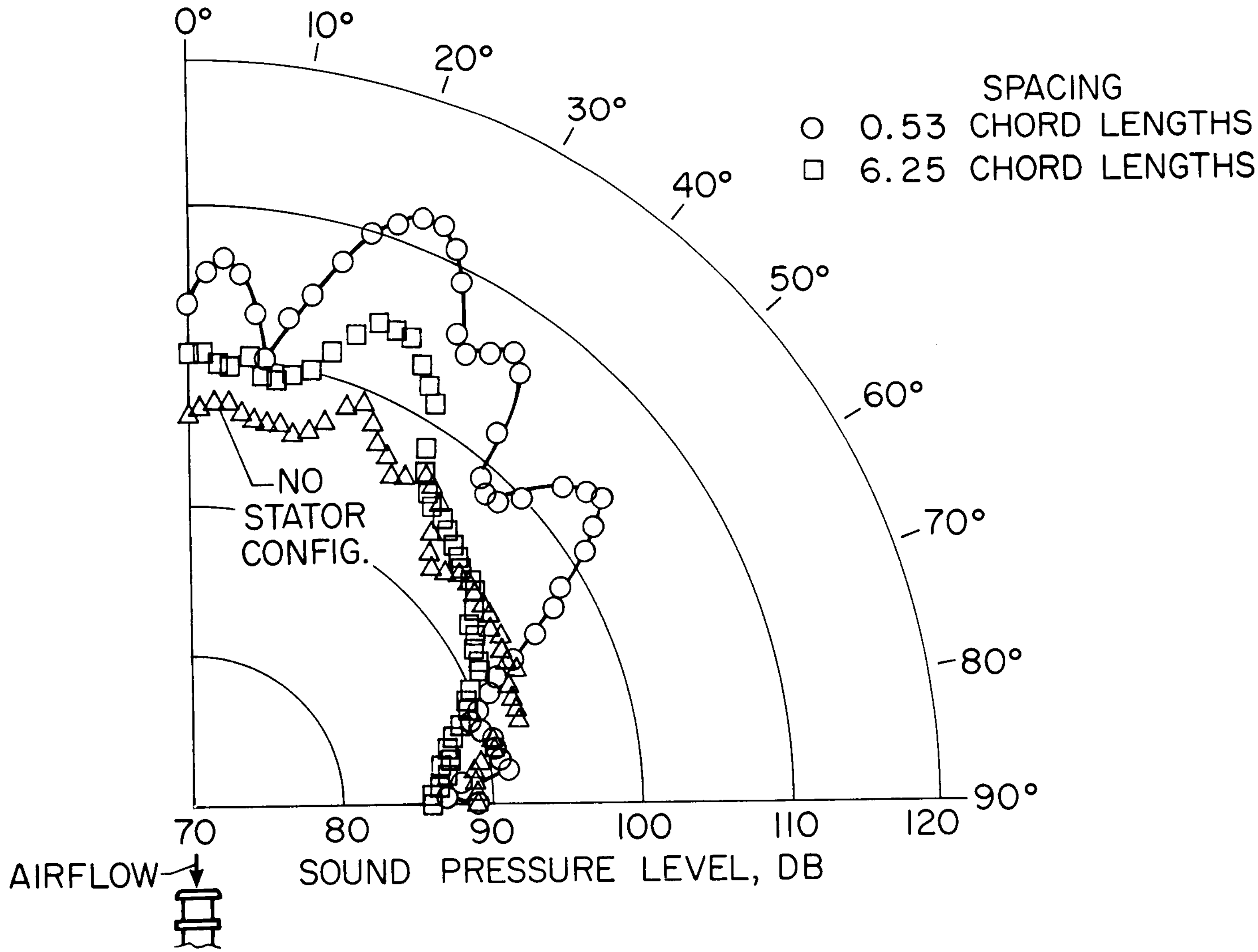

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Figure 8.- Effect of rotor-stator spacing on one-third octave band radiation patterns for 62 vane stator configuration, 8150 rpm.

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