EXPERIMENTAL NOISE STUDIES OF

INLET-GUIDE-VANE-ROTOR-STATOR INTERACTIONS FOR A

SINGLE-STAGE AXIAL-FLOW COMPRESSOR

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INTRODUCTION

Studies of noise generation in axial-flow compressors have shown that the predominant source of discrete frequency noise is the interaction between the velocity fields of the fixed and moving surfaces (stators and rotors). (See refs. 1, 2, and 3.) The theoretical studies of reference 1, which indicated that the far field radiation patterns are affected by the relative number of rotor blades and inlet guide vanes, have been substantiated by experimental work on a single-stage compressor in references 2 and 3. The experimental data also showed an appreciable reduction in sound pressure level of the discrete tone due to increased inlet-guide-vane-rotor spacing.

The theoretical treatment in reference 1 indicates that the physical characteristics of the noise field for the inlet-guide-vane-rotor combination are the same as those for the rotor-stator combination but gives no indication of the absolute magnitude of the noise. Information in this paper is concerned with the extension of the experimental work to include consideration of the rotor-stator interaction noise as well as the inlet-guide-vane-rotor interaction noise.

APPARATUS AND PROCEDURE

Test Setup

A photograph of the single-stage test compressor in an anechoic test cell is shown in figure 1. The insert in figure 1 is a section view of the inlet-guide-vane, rotor, and stator mounted in an annular shaped airflow duct. The inlet-guide-vane (I.G.V.) assembly used for the tests described in this paper had 62 vanes. However, results from other I.G.V. assemblies having 31 and 53 vanes, respectively, have also been obtained. The rotor, which was taken from one stage of a multiple-stage compressor of a jet engine, had 53 blades and the stator unit had 62 vanes. For the basic test setup the spacing between the I.G.V. and rotor and between the rotor and stator was the same (0.50 blade chord). The guide vane chord, rotor blade chord, and stator vane chord were the same (0.70 inch). Provisions were made for varying the I.G.V.-rotor spacing configurations. This paper gives noise measurement results for configurations of rotor alone, I.G.V.-rotor, rotor-stator, and I.G.V.-rotor-stator.

The compressor was driven by a 52-hp variable-speed electric motor at speeds up to 8,250 rpm which corresponds to a rotor tip speed of 530 fps.

The acoustic data were obtained by a single microphone that traversed, at a constant rate of speed, one quadrant of a 12-foot-radius azimuth circle and in a horizontal plane containing the inlet center line. All acoustic data were recorded on magnetic tape. The overall response of the system from 20 cps to 10,000 cps, considered adequate for the blade passage frequency, was flat within ±2 dB. For purposes of analysis, the tape recordings were played back into a 10-percent bandwidth filter analyzer and a graphic level recorder.

Aerodynamic Performance Data

This single-stage compressor was designed such that efficient aerodynamic operation was obtained over the range tested. Figure 2 is a plot of weight flow in lb/sec, as a function of compressor rpm, for the range tested. Airflow measurements were made by an array of pitot static tubes located forward of the I.G.V. as indicated in the sketch at the top of the figure. Since the rotor blade angles were fixed, the only way to change the airflow for the rotor alone was a change in rotor rpm. On the other hand, the weight flow for the rotor with I.G.V. could be varied by changing the turning angle of the I.G.V. For the data presented herein, the I.G.V. and the stator vanes were set at or near zero turning angle so that there were only small differences in the mean flow conditions at the rotor, that is, the rotor operated at approximately the same turning angle and power absorption for all configurations. The weight flow for the rotor alone was a maximum, represented by the upper boundary of the hatched area, and the weight flow for the I.G.V.-rotor-stator configuration was a minimum, represented by the lower boundary of the hatched area. The weight flow for the I.G.V.-rotor and the rotor-stator configurations fell about halfway between the two extremes. This decrease in weight flow with either the I.G.V. or stator in place is probably due to blockage.

RESULTS AND DISCUSSION

The acoustic data presented in this paper are in the form of noise radiation patterns showing the sound pressure level as a function of azimuth angle. These noise radiation patterns were obtained with a narrow band filter analyzer centered at the fundamental blade passage frequency.

In figure 3 are plotted noise radiation patterns for the rotor alone and for the I.G.V.-rotor combination with and without I.G.V.-rotor spacing. It can be seen that a large increase in noise level occurs as a result of adding the I.G.V. However, the higher noise levels generated due to the I.G.V.-rotor combination are seen to be reduced considerably by increasing the spacing between the I.G.V. and the rotor (to 6.25 chords in this case). These data have been reported on previously (see refs. 2 and 3) and when compared with radiation patterns calculated by the method of reference 1 were shown to be generally in good qualitative agreement.

The noise generation, or that part due to interaction (that is, the interaction noise) that we are concerned with here, is believed to be caused by periodic lift fluctuations due to velocity variations in the flow. Figure 4 shows the calculated wake width and the defect in velocity along the center line of the wake as a function of the distance behind the trailing edge of an airfoil, as calculated by the method given in reference 4. These calculated wake profiles are a function of the profile drag and do not take account of lift. Experimental data in reference 4 indicate that the wake is displaced downward with an increase in angle of attack (increase in lift) but that the reduction in velocity (velocity defect) in the wake with lift is relatively small up to near the stall angle. This figure indicates that an airfoil (that is, rotor blade) cutting through the wake of an upstream airfoil (that is, I.G.V.) experiences a relatively narrow region of velocity defect when close behind the upstream airfoil but that the wake increases in width and the defect in velocity decreases as the distance downstream of the I.G.V. increases. In fact far downstream the rotor would see essentially no velocity defect. The velocity along the center line of the wake is only 85 percent of stream velocity when the rotor is 0.50 chord behind the trailing edge of the airfoil while at 6.25 chords behind the trailing edge of the airfoil the velocity along the center line is 98 percent of stream velocity. The lift fluctuations due to velocity variations in the flow field will decrease as the spacing is increased and the associated interaction noise will also decrease. Results previously reported (see refs. 1 and 2) indicated that a spacer ring separating the I.G.V. and rotor by 6.25 chords reduced the noise level almost to that obtained with rotor alone and that further increases in spacing, in general, had only small effects on the noise level.

The preceding discussion has considered the case of the I.G.V.-rotor combination and its noise generating phenomena. It is of interest to next examine the case of the rotor and downstream stator and to compare the resultant velocities and noise levels of the two configurations. It has been pointed out that the theory (see ref. 1) predicts identical noise pressure structures for the I.G.V.-rotor as for the rotor-stator, but the theoretical treatment gives only qualitative and not quantitative results. Some insight into the interaction noise produced for these two cases can be obtained from an examination of the diagrams of the resultant velocities as shown in figure 5.

The average axial velocity through the duct for the several configurations tested was 190 ft/sec when operating at 8,250 rotor rpm. This is the resultant velocity at the I.G.V. If the I.G.V. is set at zero turning angle, the velocity relative to the rotor (0.9 radius and neglecting reduced velocities in the wake of I.G.V.) as shown on the figure is 517 ft/sec. The effect of the velocity defect in the wake of the I.G.V. on the resultant velocity at the rotor is small (about 2-percent reduction at 0.5 chord behind the trailing edge where $V_1 = 0.85V_o$). The chief resulting effect of the variations in velocity on the rotor blade is to increase the incidence angle. For the example shown on the figure, the inlet air angle relative to the rotor is increased by approximately 3° when the rotor passes through the wake of the I.G.V. at a distance of 0.5 chord lengths behind the trailing edge of the I.G.V. (where $V_1 = 0.85V_o$). This change in incidence angle is of the same order of magnitude as the total rotor blade incidence angle in uniform flow. Next, consider the resulting velocity on the downstream stator. The action of the rotor turns the stream in the tangential direction (V_{tan} at 0.9 radius) 133 ft/sec; therefore, the resultant velocity at the stator vanes is 232 ft/sec. Now, even though the wake behind the I.G.V. or behind the rotor blade is of the same form for equal distances downstream, the data suggest that the magnitude of the aerodynamic forces differs greatly. The rotor cutting through the wake of the I.G.V. at a much higher velocity (relative vel. = 517 ft/sec) than the velocity impingement from the rotor blades on the stator vanes (232 ft/sec) results in a much higher aerodynamic force for the I.G.V.-rotor setup than results from the rotor-stator combination. On this basis the interaction noise might be expected to be relatively greater for the I.G.V.-rotor combination than for the rotor-stator combination.

To further illustrate this phenomenon, some experimental results are presented in the next two figures. Figure 6 compares the radiation patterns of rotor alone with that of a rotor and downstream stator. The results shown indicate there is very little change in noise levels, or in the radiation patterns for the rotor alone and the rotor-stator combination. For this configuration and at this speed (8,250 rotor rpm), the interaction noise for the rotor-stator combination is small. However, when an I.G.V. assembly is combined with the rotor-stator, a considerable increase in the noise levels and change in radiation patterns may be observed. Figure 7 compares the results of rotor-stator combination and the I.G.V.-rotor-stator configuration. It can be seen that the noise levels are markedly increased for the I.G.V.-rotor-stator configuration over that for the rotor-stator combination. The results obtained from this configuration (I.G.V.-rotor-stator) show the radiation patterns and the magnitude of the noise levels to be about the same as those shown in figure 3 for the I.G.V.-rotor combination. As in the case of the I.G.V.-rotor combination, a 6.25-chord spacer ring was used to separate the I.G.V. and rotor. The results obtained from these tests using the spacer ring are also plotted in figure 7. It can be observed that a large reduction in noise levels also occurs when increased spacing is used in this latter configuration. The noise reductions are of the same order of magnitude for both the I.G.V.-rotor and the I.G.V.-rotor-stator configurations. The results of this investigation indicate that the major sources of the interaction noise are the aerodynamic interactions of the I.G.V. and rotor. The aerodynamic interaction of the rotor and stator are relatively weaker and the noise produced is also less.

It should be pointed out that for a multistage compressor the "stator-rotor" interactions may be more important than the "rotor-stator" interactions for a single-stage compressor.

CONCLUDING REMARKS

For the configurations studied the radiated noise levels due to the interactions of rotor and downstream stator vanes are appreciably less than those due to inlet guide vane and rotor interactions. It has been possible to correlate variations in the noise levels with a knowledge of local flow conditions in the vicinity of the blades.

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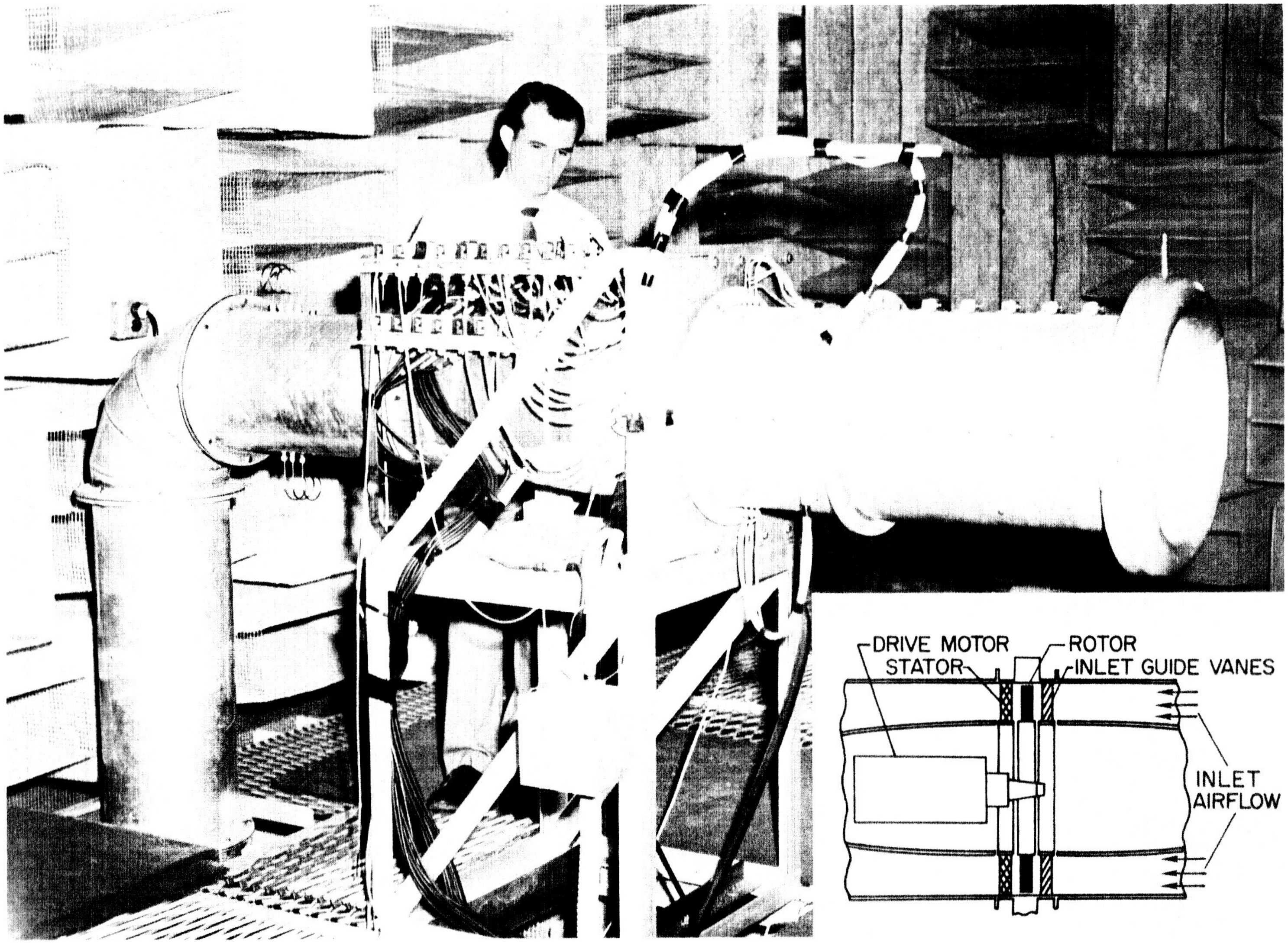

Figure 1.- Test setup in anechoic chamber.

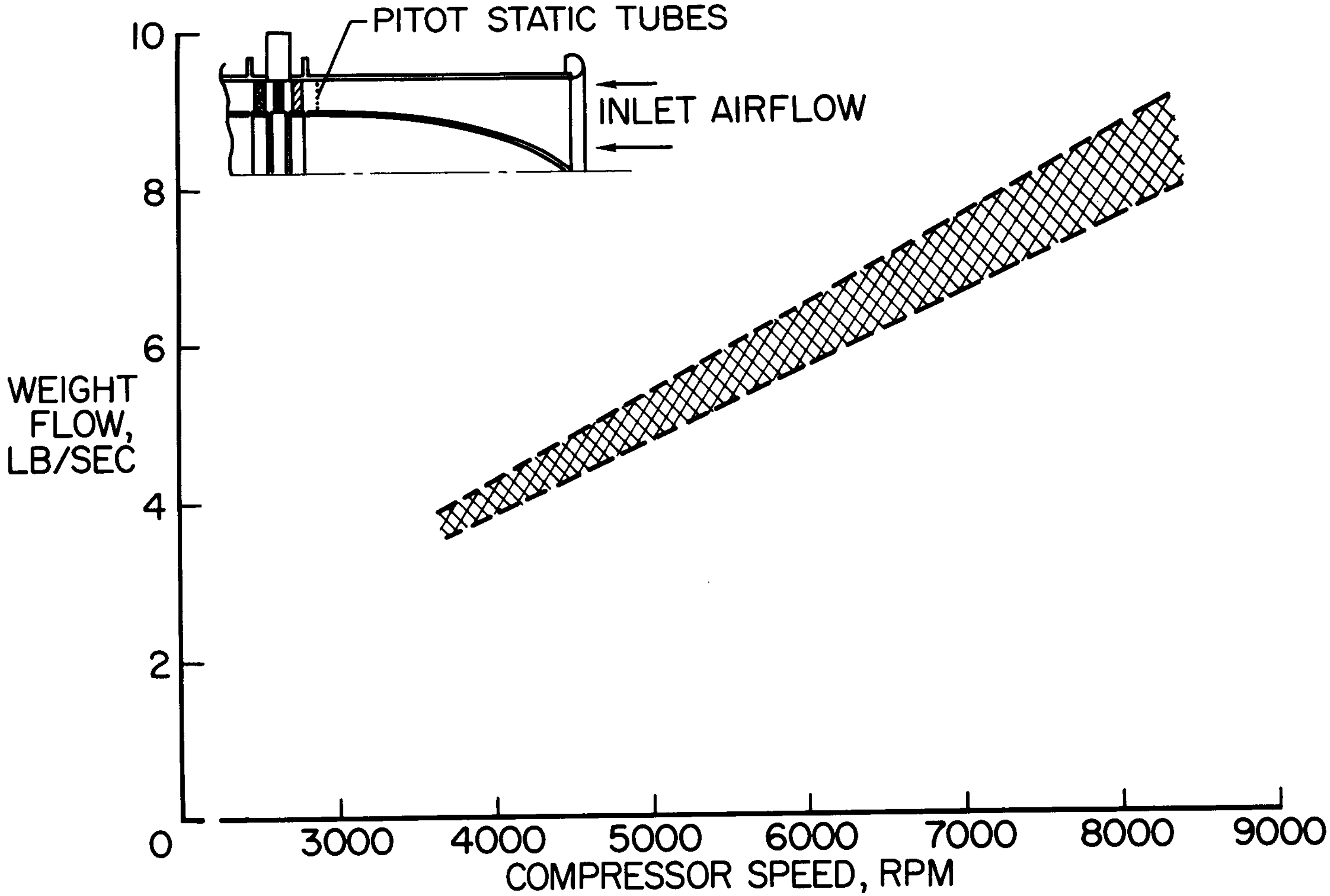

Figure 2.- Range of weight flows for all configurations.

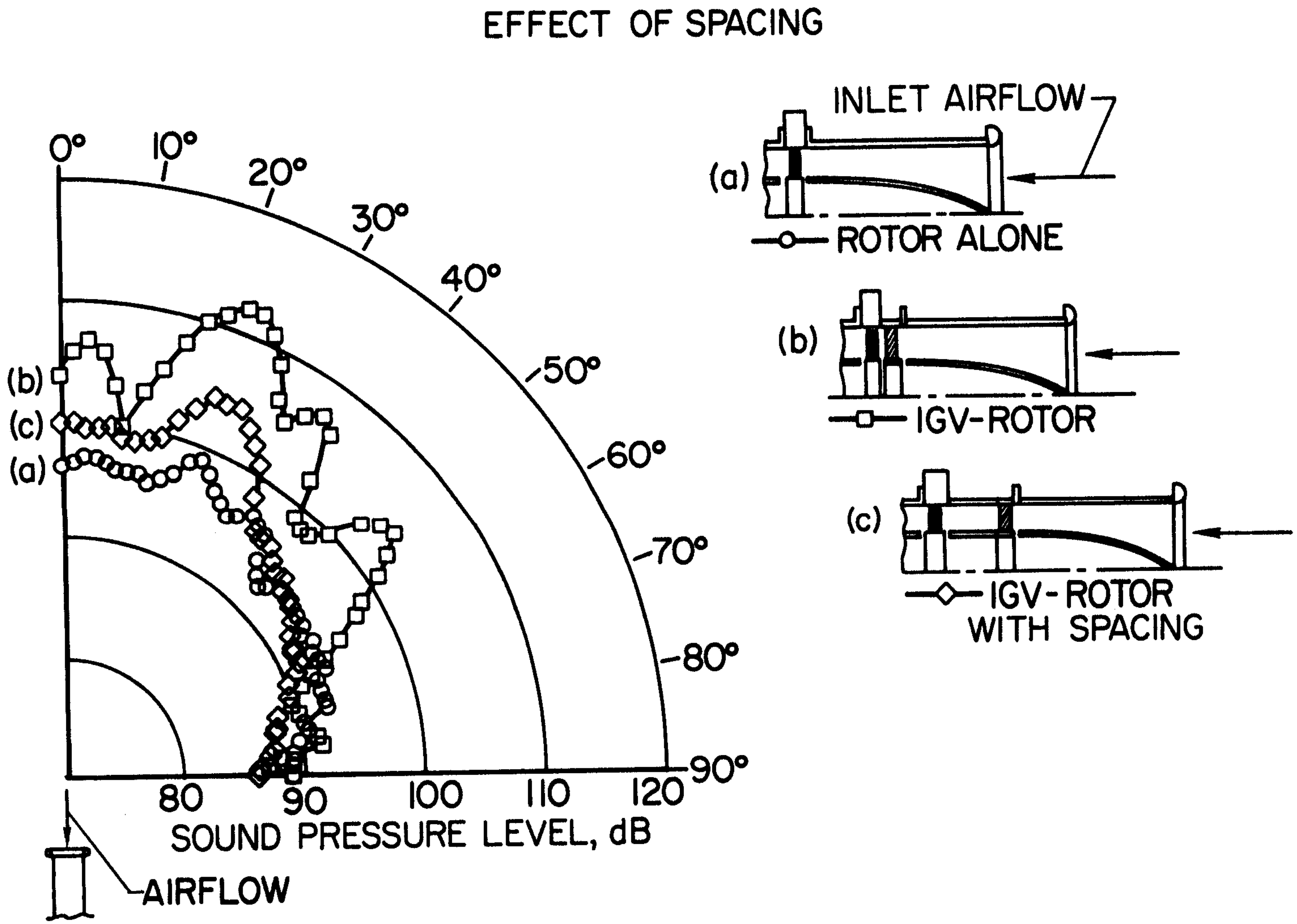

Figure 3.- Radiation patterns (narrow band analysis at fundamental blade passage frequency).

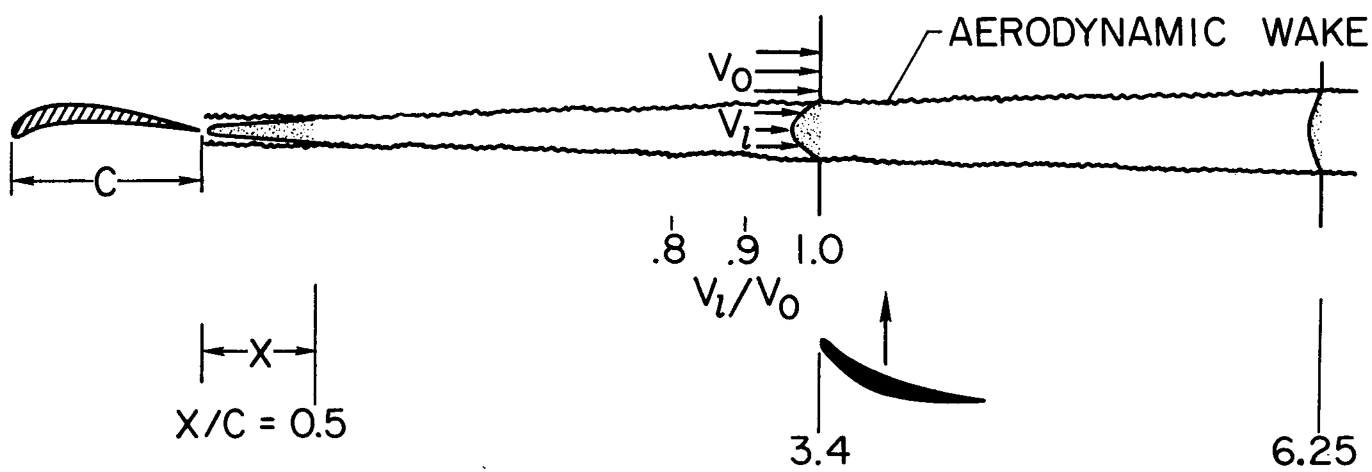

Figure 4.- Wake velocity defects at different spacings.

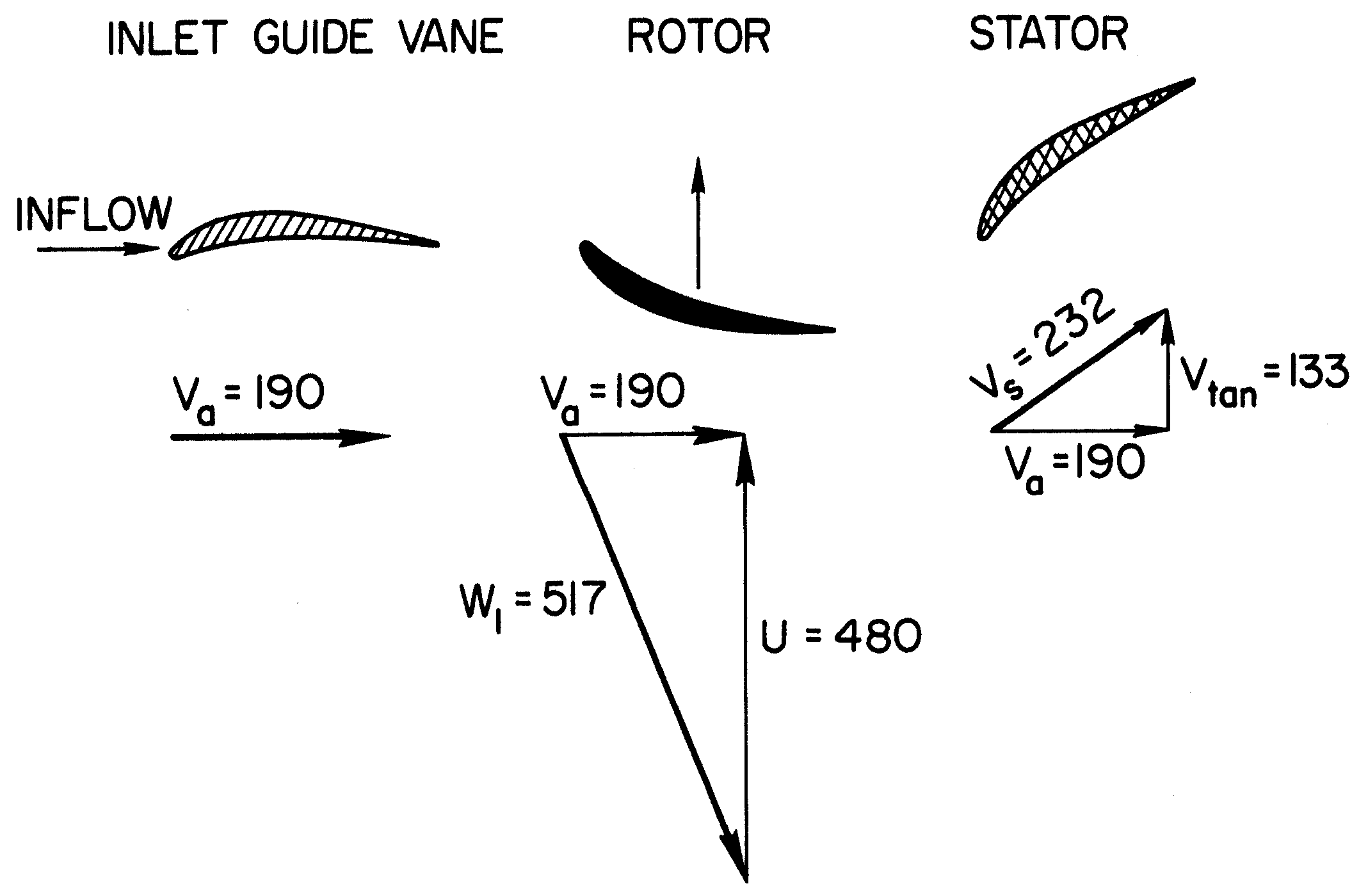

Figure 5.- Resultant velocity through compressor indicating cutting of the wake (0.90 tip radius).

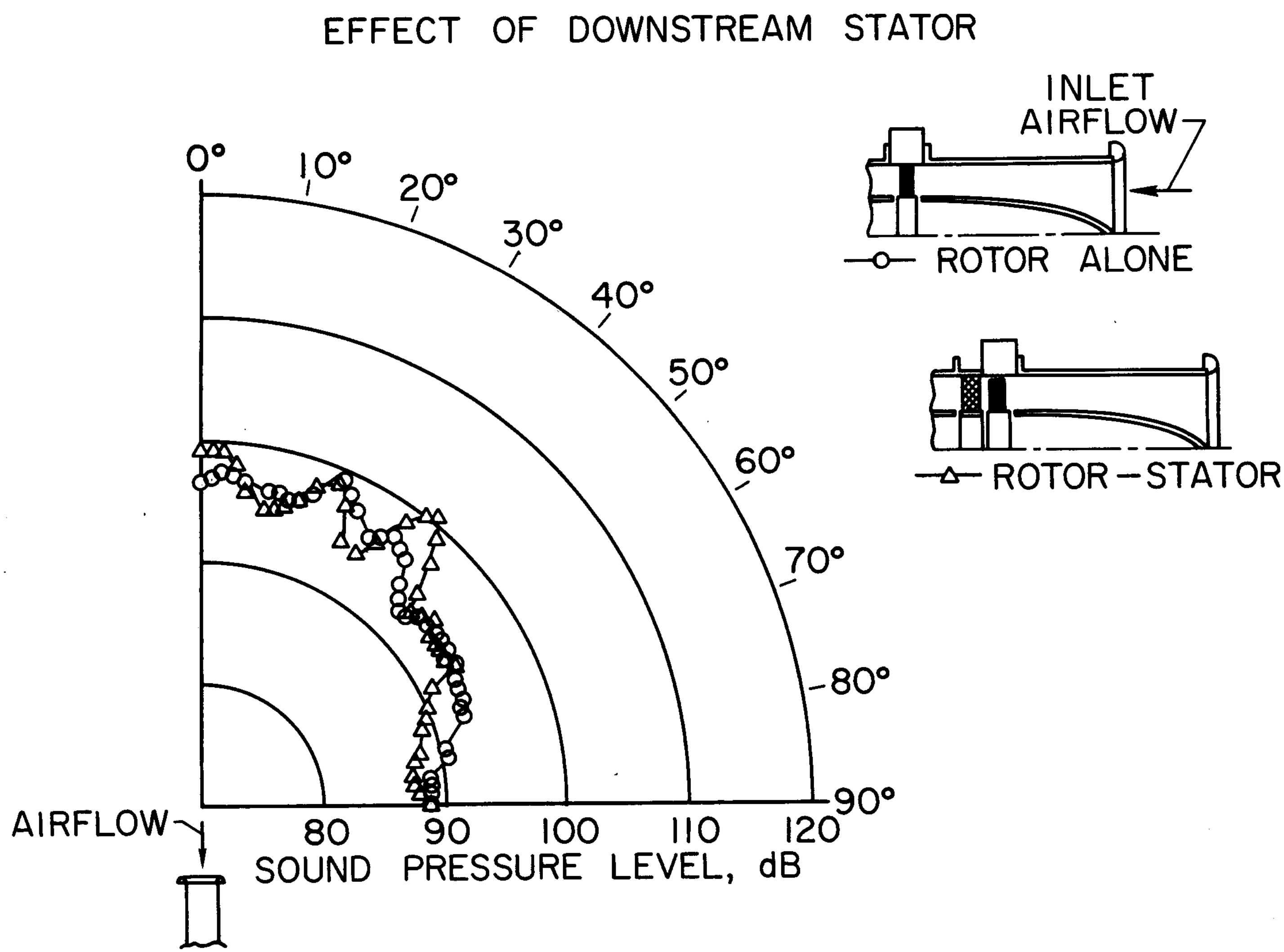

Figure 6.- Radiation patterns (narrow band analysis at fundamental blade passage frequency).

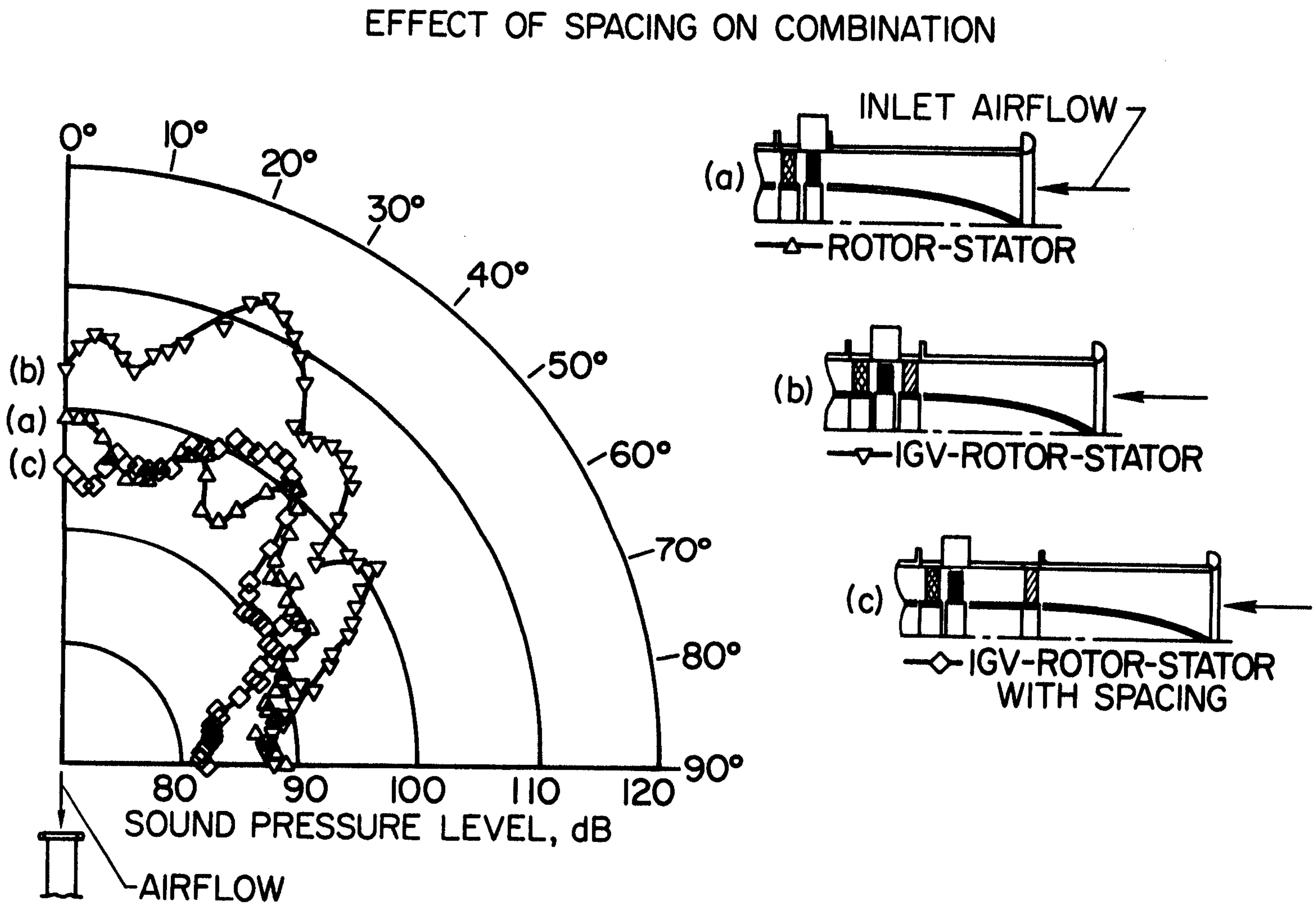

Figure 7.- Radiation patterns (narrow band analysis at fundamental blade passage frequency).

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