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EFFECTS OF INLET-GUIDE-VANE CONFIGURATION AND RELATIVE BLADE VELOCITY ON NOISE FROM AXIAL-FLOW COMPRESSORS

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16. Abstract

Studies on the effects of change of relative blade velocity, pressure ratio, inlet-guide-vane choking, and the spacing of the inlet guide vanes and rotor have been made with a specially designed axial-flow research compressor. A three-stage transonic compressor configuration and a single-stage subsonic compressor configuration were used in this investigation.

Experimental data are presented which indicate that pressure ratio is the dominant parameter in compressor noise production. Relative blade velocities were found to be important but to a lesser degree. Rotational speed, in itself, was found to be independent of noise production. Choking of the airflow in the inlet guide vanes of the transonic compressor resulted in overall noise reduction of 25 to 30 dB at compressor speeds as low as 72 percent of design rpm. Increasing the axial spacing of the inlet guide vanes on the three-stage transonic compressor resulted in noise reductions which were in general agreement with previous investigations on subsonic compressors.

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EFFECTS OF INLET-GUIDE-VANE CONFIGURATION AND RELATIVE

BLADE VELOCITY ON NOISE FROM AXIAL-FLOW COMPRESSORS

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SUMMARY

Noise-reduction studies involving changes of relative rotor-blade velocity, changes in pressure ratio, changes in velocity through the inlet guide vanes (including choked flow) over a range of compressor speeds, and changes in the spacing of the inlet guide vanes and rotor have been made by using a specially designed axial-flow research compressor. A three-stage transonic compressor configuration and a single-stage subsonic compressor configuration were used in this investigation. Information regarding compressor performance is also included.

The variation in overall noise was found to be strongly dependent on pressure ratio and moderately dependent on relative blade velocity as the compressor was operated at rotational speeds ranging from subsonic to supersonic. Choking in the inlet guide vanes at compressor speeds from 72 to 100 percent of design rpm resulted in overall noise reductions of 25 to 30 dB through the elimination of discrete tones associated with blade passage frequencies and all associated harmonics. The major performance loss resulting from inlet-guide-vane choking was a restriction in the airflow range over which the compressor could operate. Increasing the axial spacing of the inlet guide vanes on the three-stage transonic compressor resulted in noise reductions that were in general agreement with those of previous investigations conducted on subsonic compressors.

INTRODUCTION

Previous studies have shown that noise generated and radiated from the inlet of an axial-flow compressor is dependent upon several parameters, such as the maximum airflow velocity relative to the rotating blade (ref. 1), the maximum average axial airflow velocity in the inlet guide vanes when this velocity is near sonic (choke) (refs. 2 to 4), and the axial spacing of the inlet guide vanes ahead of the rotor (refs. 5 to 7). The purpose of the present study was to obtain additional experimental information on the effects of these parameters over an extended operating range and to investigate the effect of pressure ratio.

Tests were conducted on a single-stage subsonic compressor operated at transonic rotational velocities to determine the effects of relative blade velocity and pressure ratio

on noise radiated from its inlet. The acoustic and aerodynamic characteristics of a three-stage transonic-design axial-flow research compressor with several inlet-guide-vane configurations are defined for a range of velocities (up to sonic velocities) in the inlet guide vanes. These velocities were obtained by varying the area between the guide vanes over a large range of rotational speeds. Information was also obtained on the effects of axial spacing between the inlet guide vanes and rotor of the three-stage transonic compressor for comparison with data from subsonic compressors.

SYMBOLS

B   number of rotor blades

b   chord of inlet guide vane, feet (meters)

c   speed of sound, feet/second (meters/second)

M   Mach number

M_{av} average maximum axial Mach number for one-dimensional flow between adjacent inlet guide vanes

N   rotor shaft speed, revolutions per second

t   thickness of inlet guide vane, feet (meters)

U   rotational velocity of blade section, feet/second (meters/second)

V   velocity, feet/second (meters/second)

α air angle, degrees

β inlet-guide-vane turning angle, degrees

δ inlet-guide-vane setting angle, degrees

Subscripts:

1,2,3   first, second, and third stage, respectively

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av	average
i	inlet
max	maximum
o	outlet
R	relative
t	blade tip
x	axial direction

Abbreviations:

dB	decibels, re 0.0002 microbars
FBPF	first rotor-blade passage frequency, BN, hertz
IGV	inlet guide vane
OASPL	overall sound pressure level (500 to 25 000 hertz), decibels
PR	pressure ratio
SPL	sound pressure level, decibels

APPARATUS AND PROCEDURES

Description of Research Compressors

Single-stage subsonic and three-stage transonic configurations of an axial-flow compressor were used in this study. A typical test setup of one of these configurations is shown in figure 1. Both compressors are designed to operate at 24 850 rpm and at a rotational tip speed of 1301 ft/sec (396.5 m/sec). Both compressors have 36 inlet guide vanes and 23 first-stage rotor blades with root and tip diameters of 6 and 12 inches (152.4 and 304.8 mm), respectively, at the entrance to the rotor. The three-stage compressor has a design airflow of 25 lbm/sec (11.34 kg/sec) at a pressure ratio of 3 (first-stage pressure ratio of 1.38). The second- and third-stage rotors have 31 and 47 blades,

respectively. Design data, including vector diagrams, for the first stage of the transonic compressor are presented in tables I and II of reference 2. The single-stage subsonic compressor has a design airflow of 20 lbm/sec (9.07 kg/sec) at a pressure ratio of 1.09 and at maximum compressor efficiency. Also, it was designed for a pressure ratio of 1.205 at an airflow of 18.2 lbm/sec (8.25 kg/sec), but at a minimum compressor efficiency. This compressor was designed especially for noise studies to operate at a maximum relative Mach number V_R/c (see fig. 2) of 0.87, and as a result the design pressure ratio is quite low. The compressor incorporates inlet guide vanes which provide solid-body swirl distribution to the rotor, and the rotor incorporates a forced vortex-type tangential velocity distribution. The inlet guide vane angularity was varied while the compressor was operating to produce a range of relative velocities and pressure ratios. Design data, including vector diagrams, for the single-stage compressor are presented in tables I and II.

Symmetrical guide vanes with thickness-chord ratios t/b of 0.12 and 0.24 were tested in the transonic compressor and the results are compared with results for the original vanes with $t/b = 0.06$. The guide-vane angles were varied remotely while the compressor was operating.

The compressor inlet and microphone arrangement used in the noise tests are shown in the photograph of figure 1 along with part of the 25- by 25- by 23-ft (7.62- by 7.62- by 7.01-m) anechoic test chamber of the Langley noise research laboratory. As can be seen in the photograph, the test setup is arranged so that the noise from the compressor inlet radiates into the test chamber.

Noise Instrumentation and Measurement

The noise measurements associated with this study were obtained in a manner similar to that described in reference 2. Six 0.5-inch-diameter (12.7-mm) condenser microphones were used, and signals were recorded on a multichannel magnetic-tape recorder. The overall frequency response of the recording system was flat within ±2 dB from 500 to 40 000 Hz. The noise data were collected at a radial distance of 10 feet (3.05 m) from the compressor inlet (fig. 1). One of the microphones was used on a traveling boom for traversing 0° to 90° about the compressor center line in the horizontal plane to obtain noise radiation patterns.

Compressor Operating Procedures

The compressor was operated generally as described in reference 2. The compressor speed was varied from 74 to 86 percent of design speed for the single-stage subsonic compressor and from 70 to 100 percent of design speed for the three-stage transonic compressor. The single-stage subsonic compressor was not operated above 86 percent of design speed because of mechanical difficulties. All noise and aerodynamic data presented for either the choked or the unchoked mode of operation were obtained under conditions of constant rotational speed, temperature, and pressure.

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RESULTS AND DISCUSSION

The main variables for each of the two compressor configurations were rotor speed, pressure ratio, and inlet-guide-vane angle. In addition, the thickness and the axial location of the inlet guide vanes were varied on the three-stage transonic configuration. The single-stage subsonic configuration was used to study the importance of relative blade velocity and pressure ratio on noise generation, and the three-stage transonic configuration was used for studying choking and axial spacing of the inlet guide vanes. For each test condition, overall noise levels, radiation patterns, noise spectra, and performance measurements were obtained.

Relative Blade Velocity and Pressure Ratio

The effects of relative blade velocity and pressure ratio on the noise were studied by using the single-stage subsonic configuration. This particular configuration was designed so that the rotor rotational tip velocities could be transonic while the relative blade-tip velocities were subsonic. By changing the inlet-guide-vane angle the relative blade-tip velocity was caused to vary while the rotational speed was held constant. By this means, the angle of flow into the rotor, and hence the relative tip velocity of the rotor blade, was made the main variable of the tests. Corresponding changes in pressure ratio were noted. The vector diagram of figure 2 represents the inflow situation. The assumption is made that for each degree change in inlet-guide-vane angle there is a degree change in the turning angle of the air leaving the inlet guide vanes.

Noise measurements were obtained with the single-stage subsonic configuration for a range of operating conditions at the inlet, and the results are shown in figure 3. A typical experimental radiation pattern showing the variation of overall sound pressure level with azimuth of two different relative velocities at the rotor tip and two different pressure ratios is plotted in figure 3(a). The outer radiation pattern was obtained for a relative velocity at the rotor tip V_R of 900 ft/sec (274 m/sec) and a pressure ratio PR of 1.215. The inner radiation pattern was obtained for a relative velocity at the rotor tip V_R of 734 ft/sec (225 m/sec) and a pressure ratio PR of 1.12. In both cases, the airflow was held constant at 15.6 lbm/sec (7.08 kg/sec), and the rotational speed held constant at 22 000 rpm.

A series of experimental radiation patterns of the type shown in figure 3(a) was obtained, and the overall sound pressure level was averaged from 0° to 90°. These $(OASPL)_{av}$ data were then plotted as figure 3(b) for various relative velocities. For each rotational tip speed, the airflow was held constant while the relative blade velocity was varied. Corresponding values of pressure ratio (fig. 3(c)) were noted by changing the inlet-guide-vane angle and adjusting the back-pressure valves. The compressor was operated at stable conditions throughout these angular variations.

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Inspection of the results of figure 3(b) shows that the $(OASPL)_{av}$ increases as relative tip speed increases beyond about 750 ft/sec (229 m/sec). Below this speed all $(OASPL)_{av}$ values were found to be approximately the same, that is, about 111 dB. This value is believed to be a minimum unchoked or floor level for this particular compressor installation. The variation of the data of figure 3(b) is no more than 2 dB. These data follow approximately a V_R^4 variation with average overall sound pressure level for relative velocity.

Inspection of the results of figure 3(c) shows that the average overall sound pressure level increases as pressure ratio increases beyond a pressure ratio of approximately 1.13. A pressure ratio of 1.215 was obtained when the inlet guide vanes were varied 6^0 from their design angularity. Below the ratio of 1.13, all $(OASPL)_{av}$ values were found to be approximately the same as noted for figure 3(b). The variation of the data of figure 3(c) is no more than $1\frac{1}{2}$ dB. These data follow approximately a PR^{13} variation with average overall sound pressure level. Therefore, within the limits of this experiment, pressure ratio appears to be by far the most influential parameter in producing compressor noise.

The values of $(OASPL)_{max}$ were experimentally obtained for each relative blade velocity, regardless of the azimuth at which it occurred, and were compared with the peak noise levels calculated by using the empirical scheme given in reference 1; the results are presented in table III. In general, good agreement was found to exist between measured and calculated noise levels. It should be noted that the relative velocities and angles of attack were calculated without accounting for three-dimensional flow effects.

Inlet-Guide-Vane Choking

The ability to predict the conditions of choking in the inlet guide vanes for various cross-sectional areas and airflow rates was studied with the three-stage transonic compressor. Changes in the open cross-sectional area were obtained by (a) increasing the thickness of the inlet guide vanes and (b) varying the inlet-guide-vane setting angle. In addition, the effects of maximum axial airflow velocity near choke and at choke on inlet noise radiation patterns were determined.

Choking is said to occur when the average axial Mach number M_{av} for one-dimensional flow is 1.0. The data of figure 4 compare the calculated and the measured airflows required for choking with different areas between the inlet guide vanes in the transonic compressor. The calculated airflow required for choking was obtained by assuming that there were no boundary-layer or streamline-curvature effects. However, compressibility of the air was considered. As shown in figure 4, there is little difference between the calculated and measured airflows required to choke the inlet at a particular area. The calculated values tend to be a little lower than the measured values of airflow, but this could be due, in part, to neglecting the boundary-layer thickness in the calculations.

Effects on noise radiation.- Noise radiation patterns for the three-stage transonic configuration have been measured, and the results are presented in figure 5. These results demonstrate the effects of partial and complete choking on the overall sound pressure levels and the sound pressure levels of the first blade passage frequency. Figure 5(a) shows the compressor in a 5-chord-spaced configuration in an unchoked-flow mode. The effects of axial Mach number on these radiation patterns are shown by increasing the axial airflow to a near-choked condition as depicted in figure 5(b) and then to the completely choked condition (M_{av} = 1.0) shown in figure 5(c). Choking was accomplished by installing inlet guide vanes with t/b = 0.12 rather than the original t/b = 0.06 to provide the necessary flow area blockage to cause choking at approximately 23.5 lbm/sec (10.7 kg/sec). The possibility exists for some sound leakage to occur through the boundary layer in the sonic-barrier region, but the leakage is believed to be relatively minor in this case because the sound pressure levels of the first blade passage frequency that are found in noise spectra are very low when operating in a choked-flow mode. Comparison of figure 5(a) and figure 5(c) reveals a larger decrease in the sound pressure level of the first blade passage frequency than in the overall sound pressure level. A spectrum analysis (not shown) indicates that this is due to the fact that the first blade passage frequency is the primary contributor to the overall sound pressure level when this compressor is being operated unchoked but is a minor contributor after the compressor inlet has been choked.

Figure 6 is a summary of the results of inlet-guide-vane noise-reduction investigations at the Langley Research Center, including the results of reference 2. In figure 6, reduction in overall sound pressure level is plotted as a function of rotational speed for various ranges of inlet-guide-vane angle and thickness. Of particular interest here is the extension of choked-flow conditions to speeds at the lower end of the compressor operating range. It is shown that choking was possible at speeds throughout the normal operating range of this compressor (70 to 100 percent of design rpm). In addition, the data in figure 6 show that choked-flow conditions were achieved for each combination of inlet-guide-vane thickness and angle. The largest noise reductions (25 to 30 dB) occurred for choked-flow conditions; however, it can be seen that some noise reductions occurred before fully choked flow was achieved.

Effects on compressor performance.- In figure 7, the compressor efficiency and pressure ratio are plotted as functions of the design-corrected airflow for the 12-percent-thick inlet guide vanes with 0° vane setting and 5-chord spacing. These values are compared with those for the original 6-percent-thick guide vanes with 0° vane setting and 0.5-chord spacing, taken from reference 2. It can be seen that at a given pressure ratio there is a loss in weight flow for the thicker vanes at the lower compressor speeds, that is, 70- and 80-percent design rpm (unchoked conditions); at 92-percent speed there was a marked restriction in the available airflow range due, on the one hand, to the onset of

surge and, on the other, to choked flow. The maximum compressor efficiencies are generally the same for the vanes of both thicknesses.

Figure 8 shows performance comparisons of the 6-percent-thick and 12-percent-thick guide vanes, both at an inlet-guide-vane angle of 15° and 0.5-chord spacing. At this angle the 12-percent-thick vanes are generally more efficient than the 6-percent-thick vanes, apparently because when set at 15° the latter are operating near stall and hence have greater drag and losses in performance. The compressor operated in a satisfactory manner with the 24-percent-thick inlet guide vanes; however, data of the types shown in figures 7 and 8 are not available.

Inlet-Guide-Vane Spacing

Effects on noise spectra.- The effects of inlet-guide-vane spacing on the inlet noise spectra and noise radiation patterns were obtained for the three-stage transonic configuration. Figure 9 shows frequency spectra of the 12-percent-thick guide-vane configurations at two axial spacings with equal airflow rates and rotational speeds. These data were recorded at the 30° azimuth. The spectra presented were obtained by using 50-Hz-bandwidth analyses. Several discrete frequency peaks are present in the spectra, and the most prominent ones are identified as integral multiples of rotor-blade passage frequencies or shaft frequencies, or both. Changing the spacing of the guide vanes from 0.5 chord to 5 chords resulted in reductions in sound pressure level for several of the peaks, the largest reduction being associated with the first-stage fundamental blade passage frequency. The broadband noise floor appears to be the same regardless of the guide-vane axial spacing. The peaks denoted as multiples of shaft speed (29 N, 30 N, etc.) have the appearance of so-called combination tones which are usually associated with shock-wave formations on the blades. Such components are normally observed during operation above the critical Mach number of the rotor blades, a condition which is believed to have existed at 70-percent design rpm. These shaft-speed harmonics are generally lower in amplitude at the greater axial spacing. At higher rotational speeds, these shaft-speed harmonics are generally more prominent, as shown in figure 9(b), but the effects of spacing are similar.

Effects on noise radiation patterns.- The data of figure 10 show the effects of inlet-guide-vane spacing on the noise radiation patterns for the overall sound pressure level and the sound pressure level of the first blade passage frequency. The data of figure 10(a) show radiation patterns of overall sound pressure level for 0.5-chord spacing (outer record) and 5-chord spacing (inner record). Although the comparisons of figure 10 are for a rotational speed of 70-percent design rpm, noise reductions of the same order of magnitude were obtained at higher rotational speeds. The greatest noise reduction, approximately 10 dB, occurs at the azimuth angle of the dominant lobe, which is approximately 20°.

The data of figure 10(b) were obtained from the data of figure 10(a) by using a 1/10-octave spectrum analyzer set at a center frequency equal to the first blade passage frequency for each spacing configuration. The greatest noise reduction occurred at the same azimuth, 20°, as in the radiation patterns of overall sound pressure level shown in figure 10(a). This reduction is to be expected, since the first blade passage frequency is the dominant frequency at this test condition. Comparison of figures 10(a) and 10(b) shows that the maximum sound pressure levels of the overall noise and the first blade passage frequency are nearly the same. This comparison indicates the very strong contribution made by the first blade passage frequency to the overall sound pressure level. The maximum reduction in sound pressure level of the first blade passage frequency obtained by increasing the spacing of these inlet guide vanes was approximately 15 dB. This value is somewhat higher than the values in previously published works on the subject (refs. 2, 4, 5, 6, and 7) and may be due to the presence of a larger than normal wake defect with the thicker (12-percent-chord) inlet guide vanes.

CONCLUDING REMARKS

Noise-reduction studies involving changes of relative rotor-blade velocity, changes of pressure ratio, changes in velocity through the inlet guide vanes (including choked flow) over a range of compressor speeds, and changes in the spacing of the inlet guide vanes and rotor have been made by using a specially designed axial-flow research compressor. A three-stage transonic compressor configuration and a single-stage subsonic compressor configuration were used in this investigation.

The variation in overall noise was found to be strongly dependent on pressure ratio and moderately dependent on relative blade velocity as the compressor was operated at rotational speeds ranging from subsonic to supersonic. Choking in the inlet guide vanes at compressor speeds from 72- to 100-percent design rpm resulted in overall noise reductions of 25 to 30 dB through the elimination of blade passage frequencies and all associated harmonics. The major performance loss resulting from inlet-guide-vane choking was a restriction in the airflow range over which the compressor could operate. Increasing the axial spacing of the inlet guide vanes on the three-stage transonic compressor resulted in noise reductions that were in general agreement with those of previous investigations conducted on subsonic compressors.

Langley Research Center,
  National Aeronautics and Space Administration,
    Langley Station, Hampton, Va., September 17, 1969.

REFERENCES

1. Smith, M. J. T.; and House, M. E.: Internally Generated Noise From Gas Turbine Engines. Measurement and Prediction. Trans. ASME, Ser. A: J. Eng. Power, vol. 89, no. 2, Apr. 1967, pp. 177-190.

2. Chestnutt, David: Noise Reduction by Means of Inlet-Guide-Vane Choking in an Axial-Flow Compressor. NASA TN D-4682, 1968.

3. Sobel, J. A., III; and Welliver, A. D.: Sonic Block Silencing for Axial and Screw-Type Compressors. Noise Contr. Shock Vib., vol. 7, no. 5, Sept.-Oct. 1961, pp. 9-11.

4. Chestnutt, David; and Crigler, John L.: Potential of Inlet-Vane-Guide Configuration for Inlet Noise Reduction. Progress of NASA Research Relating to Noise Alleviation of Large Subsonic Jet Aircraft, NASA SP-189, 1968, pp. 307-317.

5. Sharland, I. J.: Sources of Noise in Axial Flow Fans. J. Sound Vib., vol. 1, no. 3, July 1964, pp. 302-322.

6. Crigler, John L.; and Copeland, W. Latham: Noise Studies of Inlet-Guide-Vane-Rotor Interaction of a Single-Stage Axial-Flow Compressor. NASA TN D-2962, 1965.

7. Crigler, John L.; Copeland, W. Latham; and Morris, Garland J.: Turbojet-Engine Noise Studies To Evaluate Effects of Inlet-Guide-Vane-Rotor Spacing. NASA TN D-4690, 1968.

## TABLE I.- BLADE DESIGN DATA FOR SINGLE-STAGE SUBSONIC COMPRESSOR

(a) Rotor with 23 blades having NACA 65-series airfoil sections

Radius		Chord		Solidity	Turning angle, deg	Thickness, percent chord	Angle of attack, deg	Setting angle, deg	Design lift coefficient
in.	m	in.	m						
5.97	0.1516	1.63	0.0414	1.00	4.2	0.06	5.2	59.3	0.248
4.53	.1151	1.63	.0414	1.32	6.9	.06	6.5	41.5	.252
3.08	.0782	1.63	.0414	1.94	3.6	.10	5.3	27.8	.000

(b) First stator with 30 vanes having NACA 65-series airfoil sections

Radius		Chord		Solidity	Turning angle, deg	Thickness, percent chord	Angle of attack, deg	Setting angle, deg	Design lift coefficient
in.	m	in.	m						
5.93	0.1506	1.242	0.0315	1.00	27.9	0.06	18.0	36.0	1.96
4.62	.1173	.967	.0246	1.00	10.6	.06	7.0	22.9	.52
3.30	.0838	.692	.0176	1.00	3.4	.06	3.0	13.7	.00

TABLE II.- VELOCITY VECTOR DIAGRAMS AND DATA FOR SUBSONIC ROTOR AT THREE BLADE STATIONS
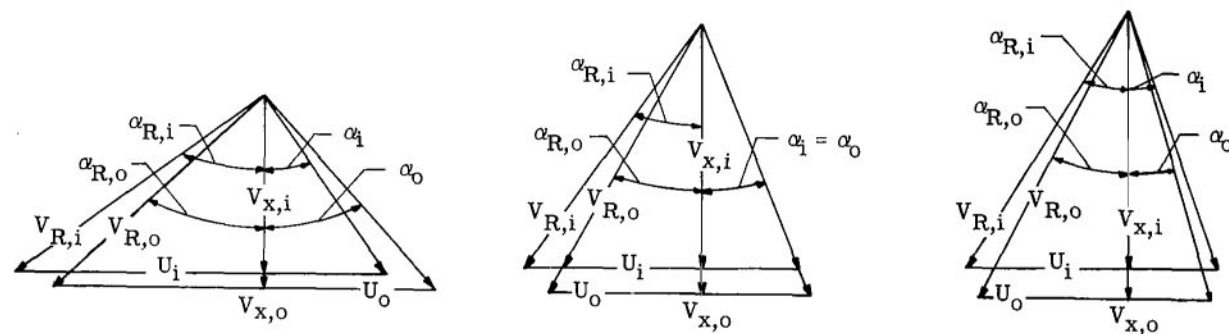
Station radius:			
Inlet	6.00 in. (152.4 mm)	4.465 in. (113.4 mm)	3.70 in. (94.0 mm)
Outlet	5.95 in. (151.1 mm)	4.59 in. (116.6 mm)	3.91 in. (99.3 mm)
$M_{x,i}$	0.369	0.539	0.594
$M_{x,o}$	0.387	0.647	0.712
$M_{R,i}$	0.871	0.800	0.771
$M_{R,o}$	0.770	0.865	0.877
M_i	0.551	0.620	0.647
M_o	0.661	0.743	0.768
U_i	1301 ft/sec (397 m/sec)	970 ft/sec (296 m/sec)	795 ft/sec (242 m/sec)
U_o	1291 ft/sec (393 m/sec)	996 ft/sec (304 m/sec)	848 ft/sec (258 m/sec)
$V_{x,i}$	400 ft/sec (122 m/sec)	581 ft/sec (177 m/sec)	637 ft/sec (194 m/sec)
$V_{x,o}$	415 ft/sec (126 m/sec)	686 ft/sec (209 m/sec)	753 ft/sec (230 m/sec)
$V_{R,i}$	946 ft/sec (288 m/sec)	861 ft/sec (262 m/sec)	800 ft/sec (244 m/sec)
$V_{R,o}$	827 ft/sec (252 m/sec)	917 ft/sec (280 m/sec)	928 ft/sec (283 m/sec)
α_i	48.0°	29.6°	23.25°
α_o	54.2°	29.6°	22.1°
$\alpha_{R,i}$	64.9°	47.6°	39.6°
$\alpha_{R,o}$	59.9°	41.5°	35.8°

TABLE III.- COMPARISON OF MEASURED AND CALCULATED NOISE LEVELS AT A DISTANCE

OF 10 FEET (3.05 m) FROM THE INLET OF THE SUBSONIC COMPRESSOR

Tip speed, U_t		β, deg	Angle of attack, deg	$V_{t,R}$		Maximum overall sound pressure level, dB	
ft/sec	m/sec			ft/sec	m/sec	Measured	Calculated
994	303	36	8.15	824	251	122	124
		42	6.65	778	237	120	122
		48	4.60	723	220	119	119
		55	.80	644	196	120	116
1040	317	36	7.55	877	267	121	125
		42	6.00	821	250	120	123
		48	3.90	763	233	120	121
		55	-.20	656	200	119	117
1100	335	42	6.15	862	263	121	125
		48	4.00	792	241	120	123
		55	.10	698	213	118	119
1150	351	36	7.30	960	293	127	129
		42	6.10	900	274	123	127
		48	4.00	832	254	121	124
		55	0	734	224	119	120
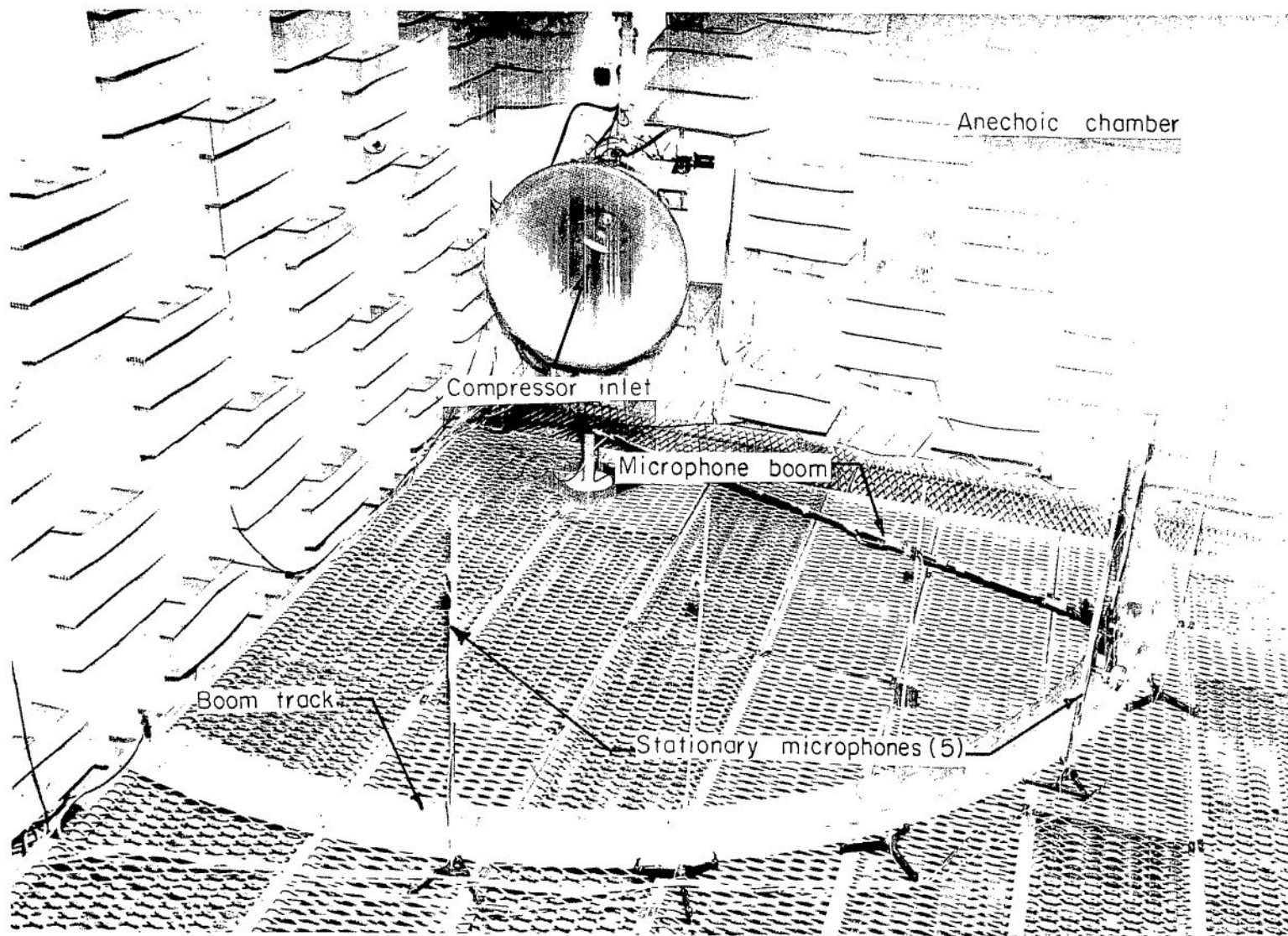
Figure 1.- Test setup in anechoic test chamber for measurement of compressor inlet noise.

L-68-5985.1

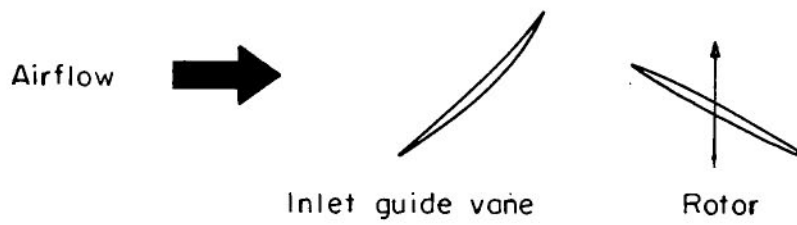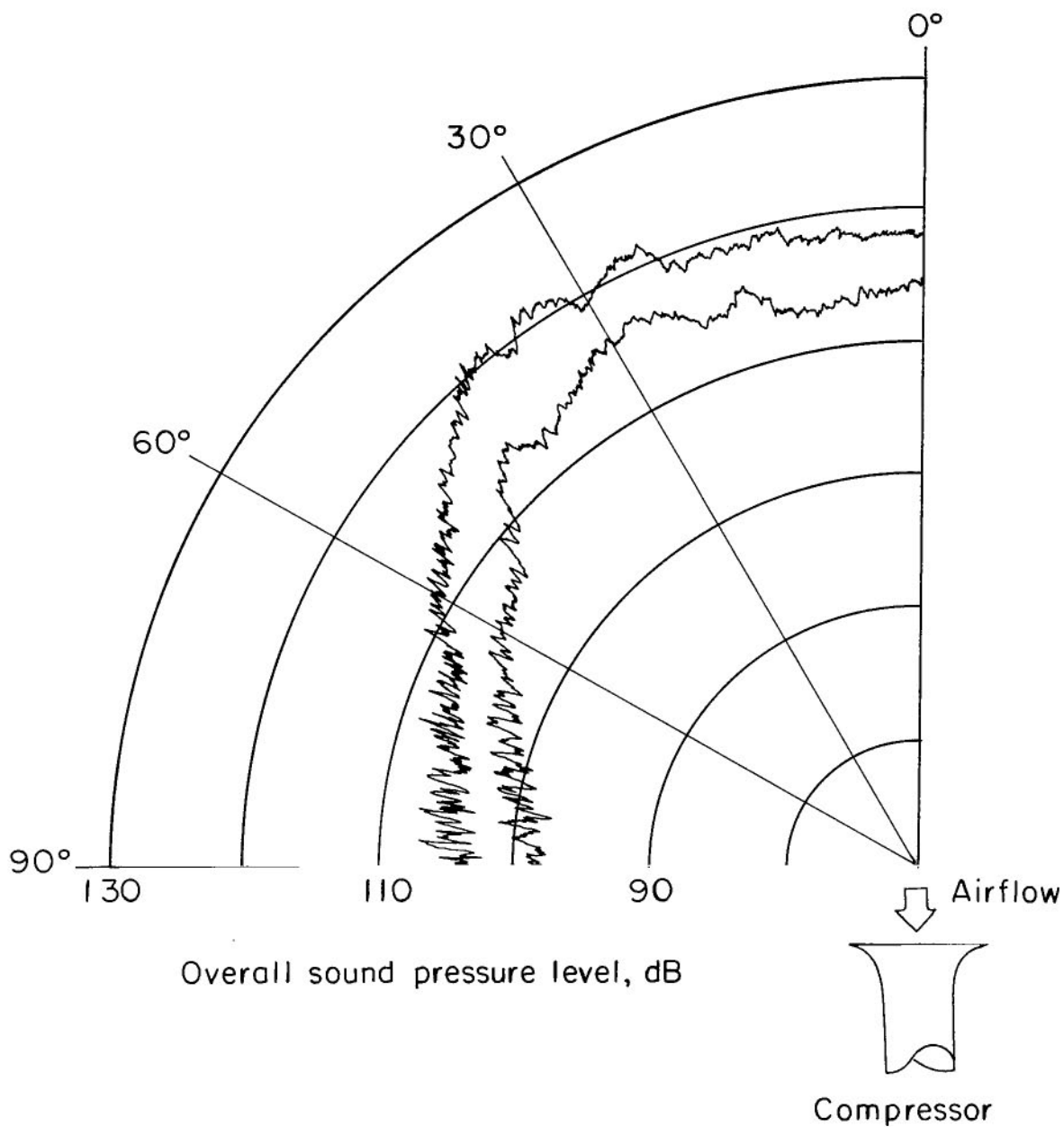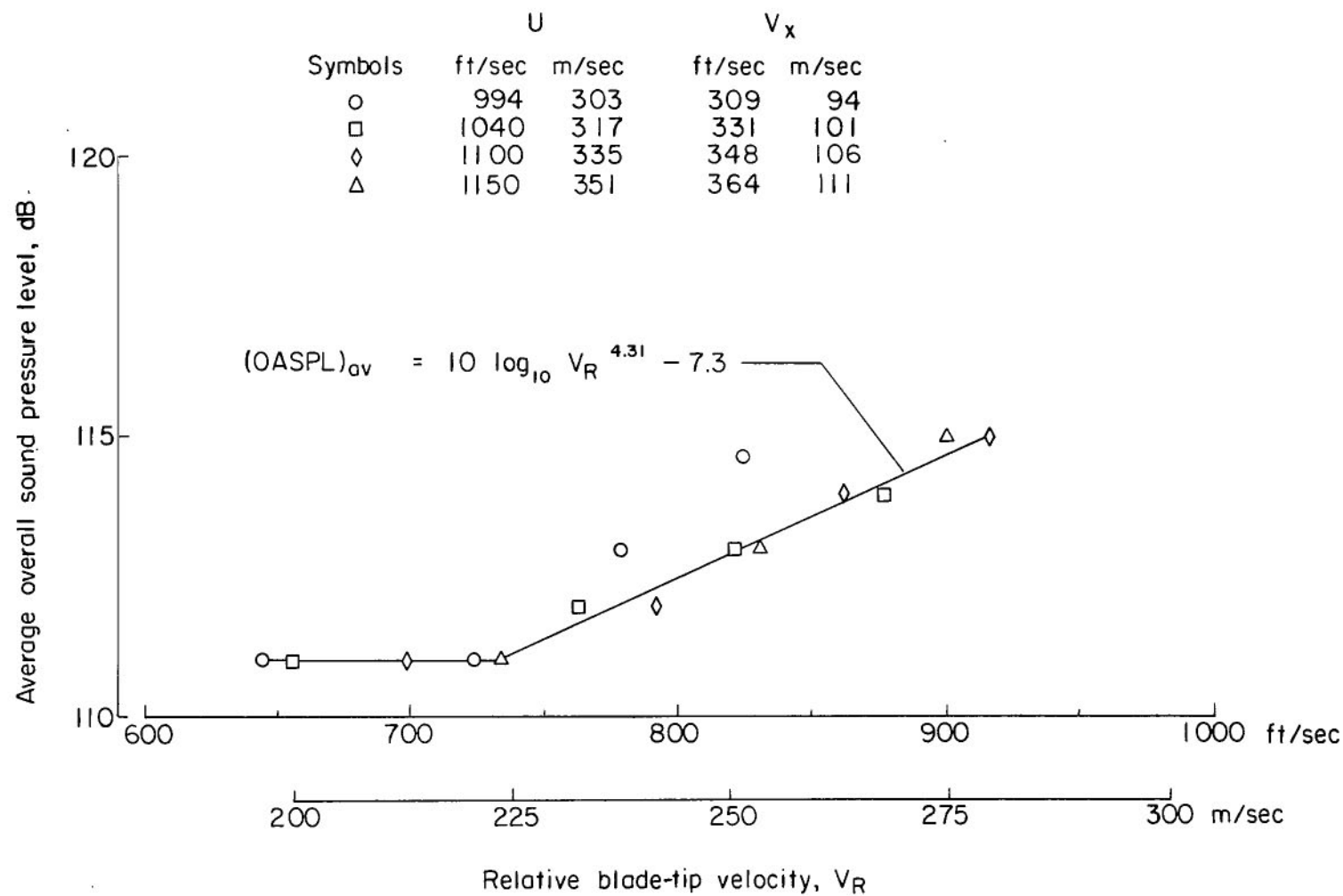Airflow ➡️

Inlet guide vane   Rotor
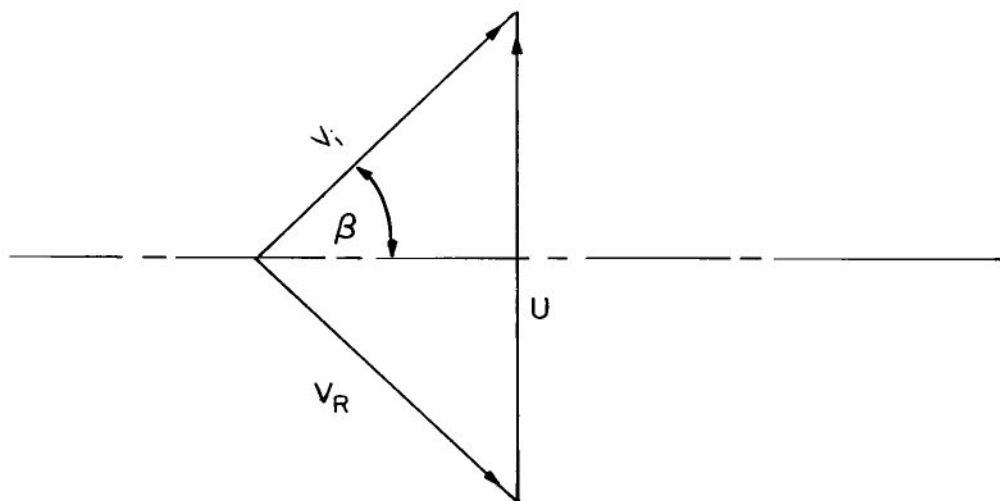
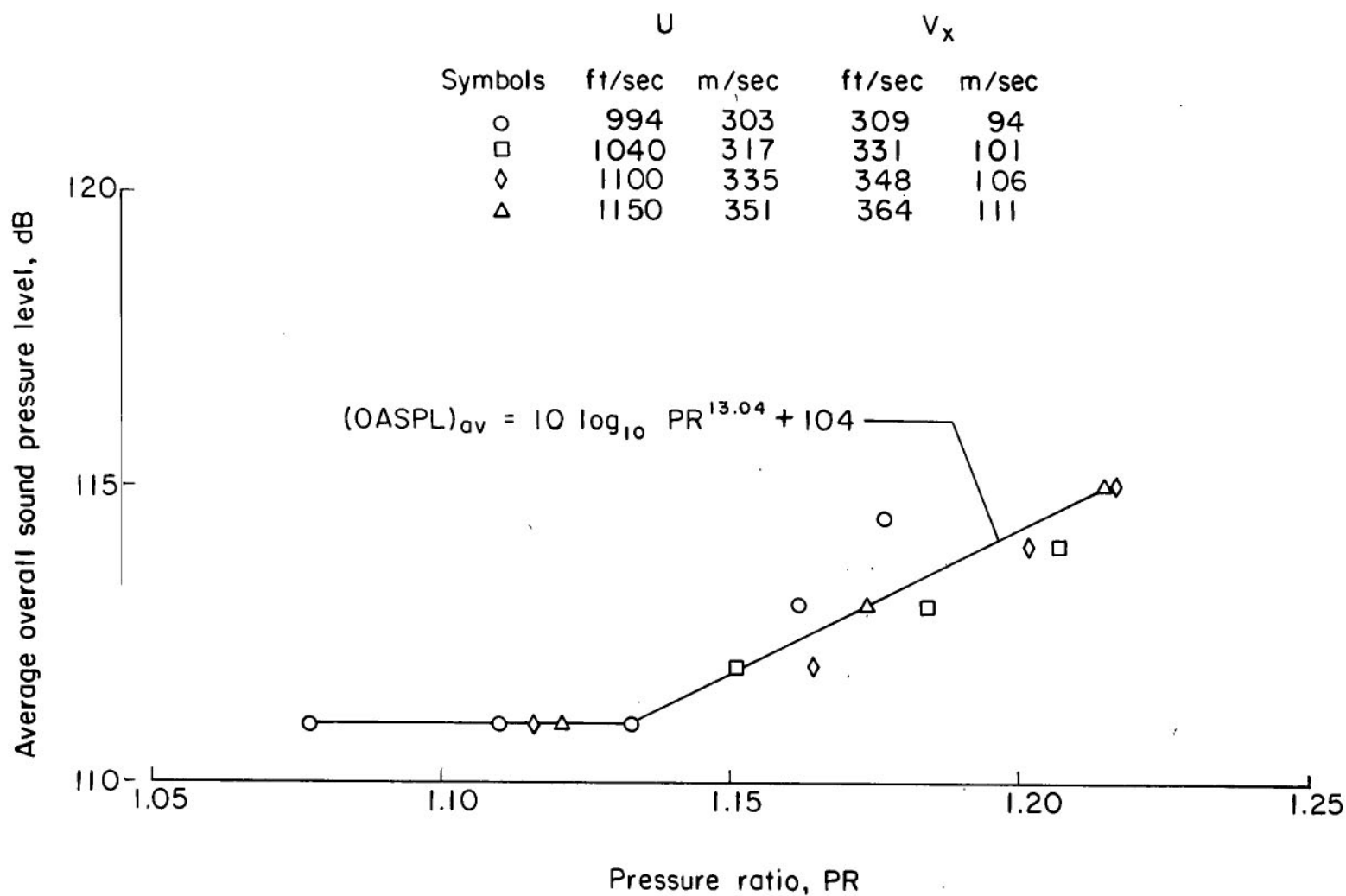Figure 2.- Vector diagram of inflow to subsonic rotor.

(a) Change in radiation pattern due to changes in pressure ratio and in relative velocity at rotor tip.

Figure 3.- Results of noise measurements with a single-stage subsonic compressor for a range of operating conditions.

Symbols	U ft/sec	U m/sec	V_x ft/sec	V_x m/sec
o	994	303	309	94
□	1040	317	331	101
◊	1100	335	348	106
△	1150	351	364	111

$$(OASPL)_{av} = 10 \log_{10} V_R^{4.31} - 7.3$$

Relative blade-tip velocity, V_R

(b) Noise-level variations at various relative blade-tip velocities and various rotor-tip velocities.

Figure 3.- Continued.

17

	U		V_x	
Symbols	ft/sec	m/sec	ft/sec	m/sec
○	994	303	309	94
□	1040	317	331	101
◇	1100	335	348	106
△	1150	351	364	111

$$(OASPL)_{av} = 10 \log_{10} PR^{13.04} + 104$$

(c) Noise-level variations at various pressure ratios and various tip velocities.

Figure 3.- Concluded.
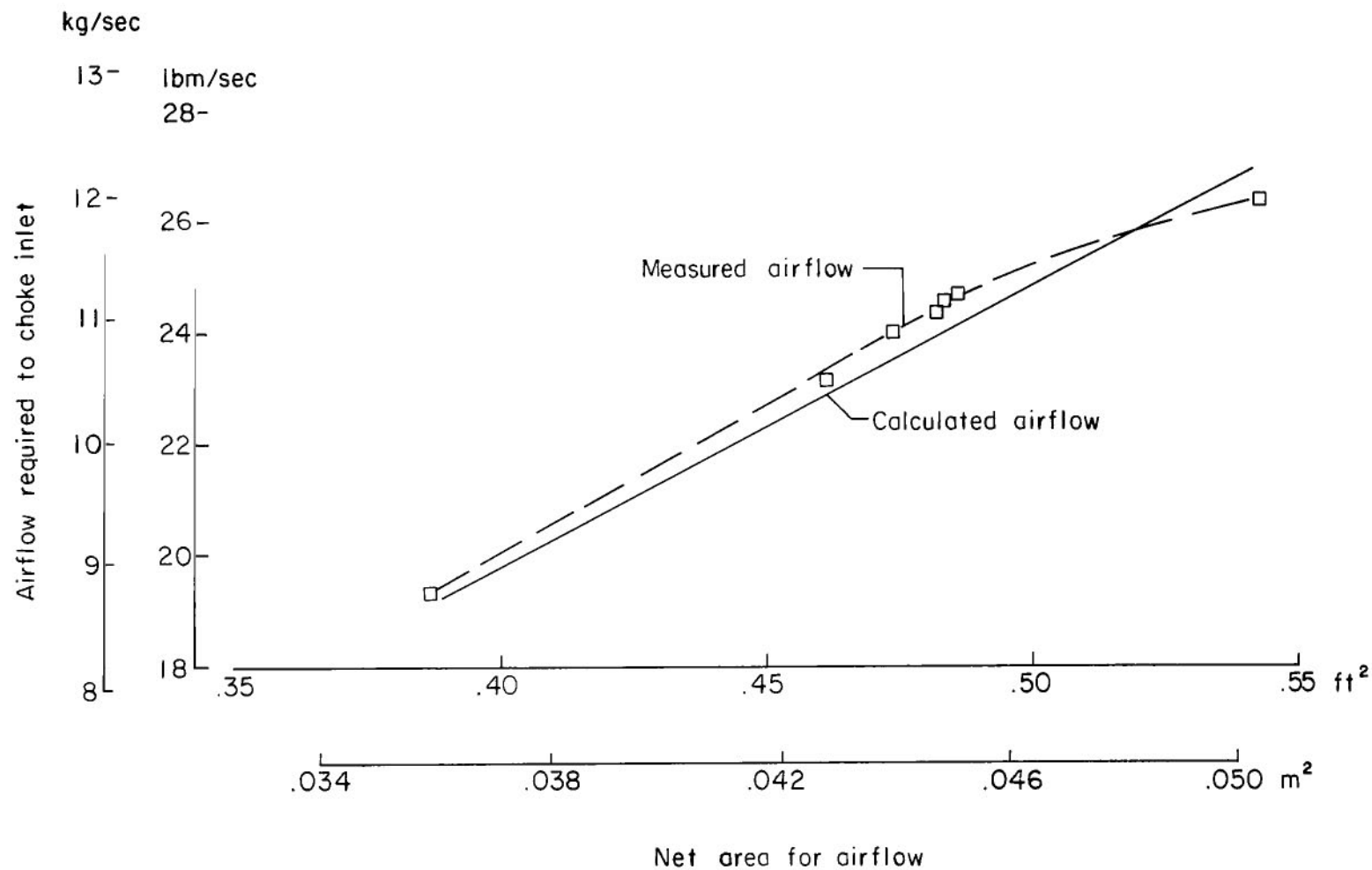
Figure 4.- Comparison of calculated and measured airflows required for choking with different airflow areas in transonic compressor.

Compressor
℄

0°

OASPL, dB

30°

FBPF SPL, dB

60°

90° 120 100   80

Sound pressure level, dB

(a) 85-percent design speed; $M_{av} = 0.58$.

0°

30°

OASPL, dB

FBPF SPL, dB

60°

90° 120   100   80

Sound pressure level, dB

(b) 90-percent design speed; $M_{av} \approx 0.9$.

0°

30°

60°

OASPL, dB

FBPF SPL, dB

90° 120   100   80

Sound pressure level, dB
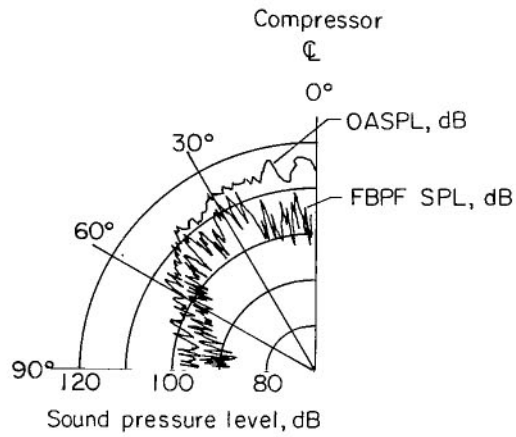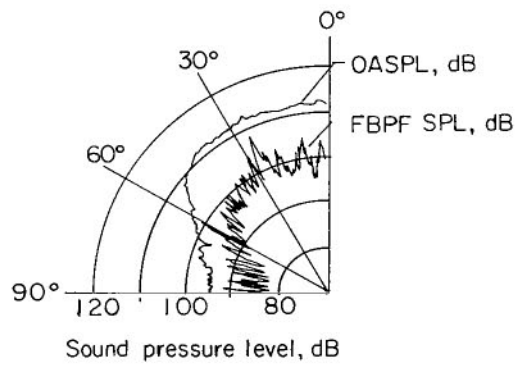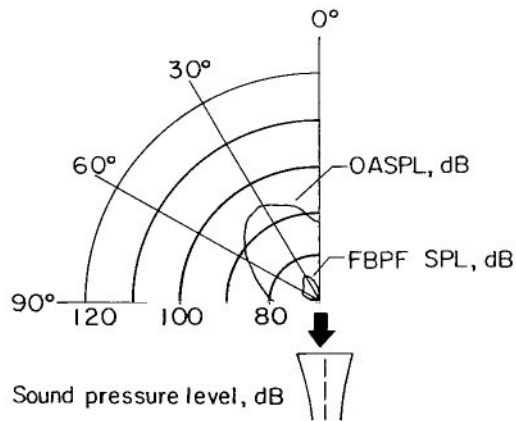
(c) 98-percent design speed; $M_{av} = 1.00$.

Figure 5.- Alteration of transonic compressor radiation patterns by M_{av}. 12-percent-thick inlet guide vanes; 0^0 inlet-guide-vane angle; inlet guide vanes at axial distance of 5 chords ahead of rotor.
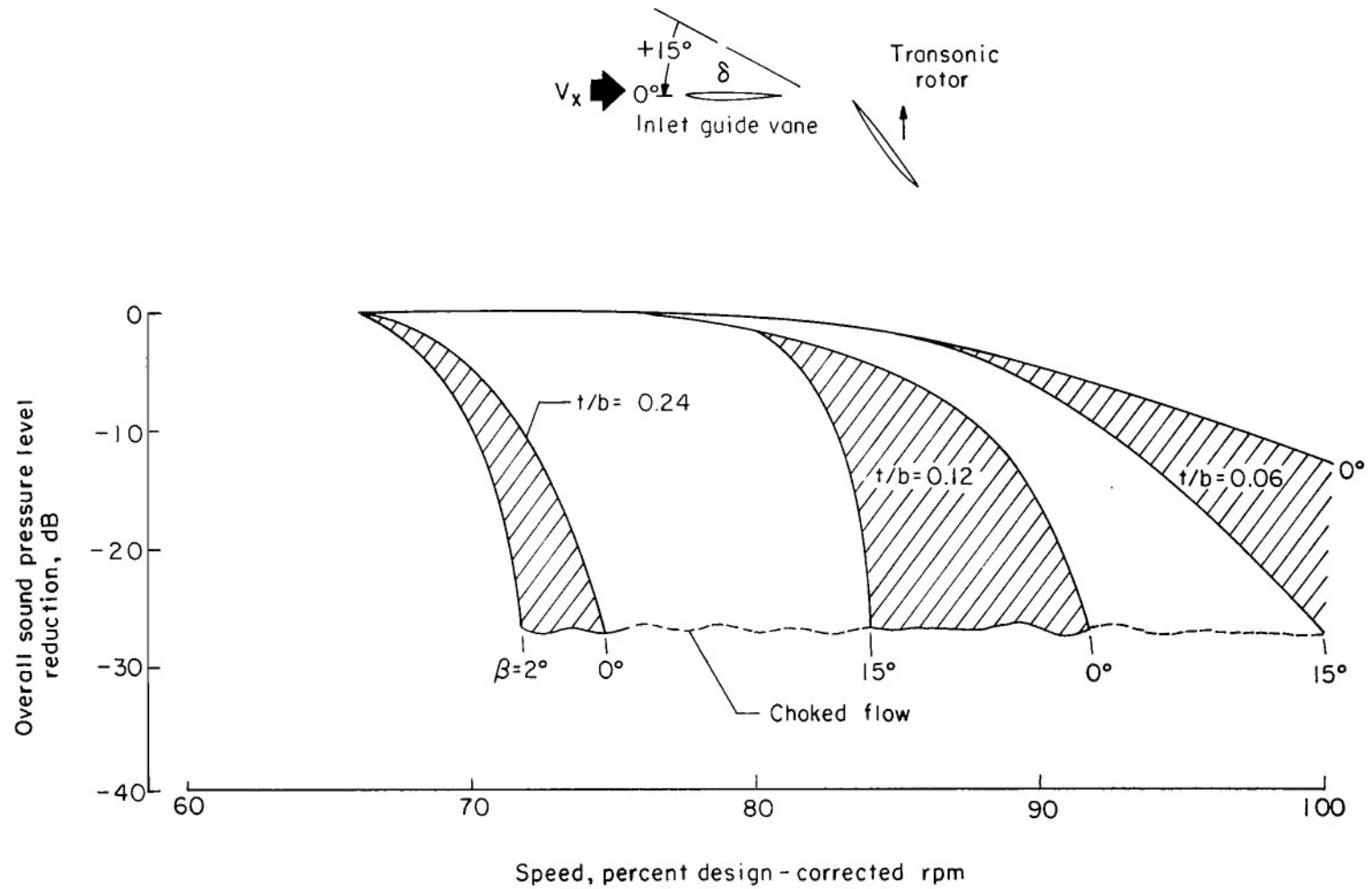
Figure 6.- Summary of reduction in overall sound pressure level for transonic compressor as a function of rotational speed and inlet configuration (0.5-chord spacing).
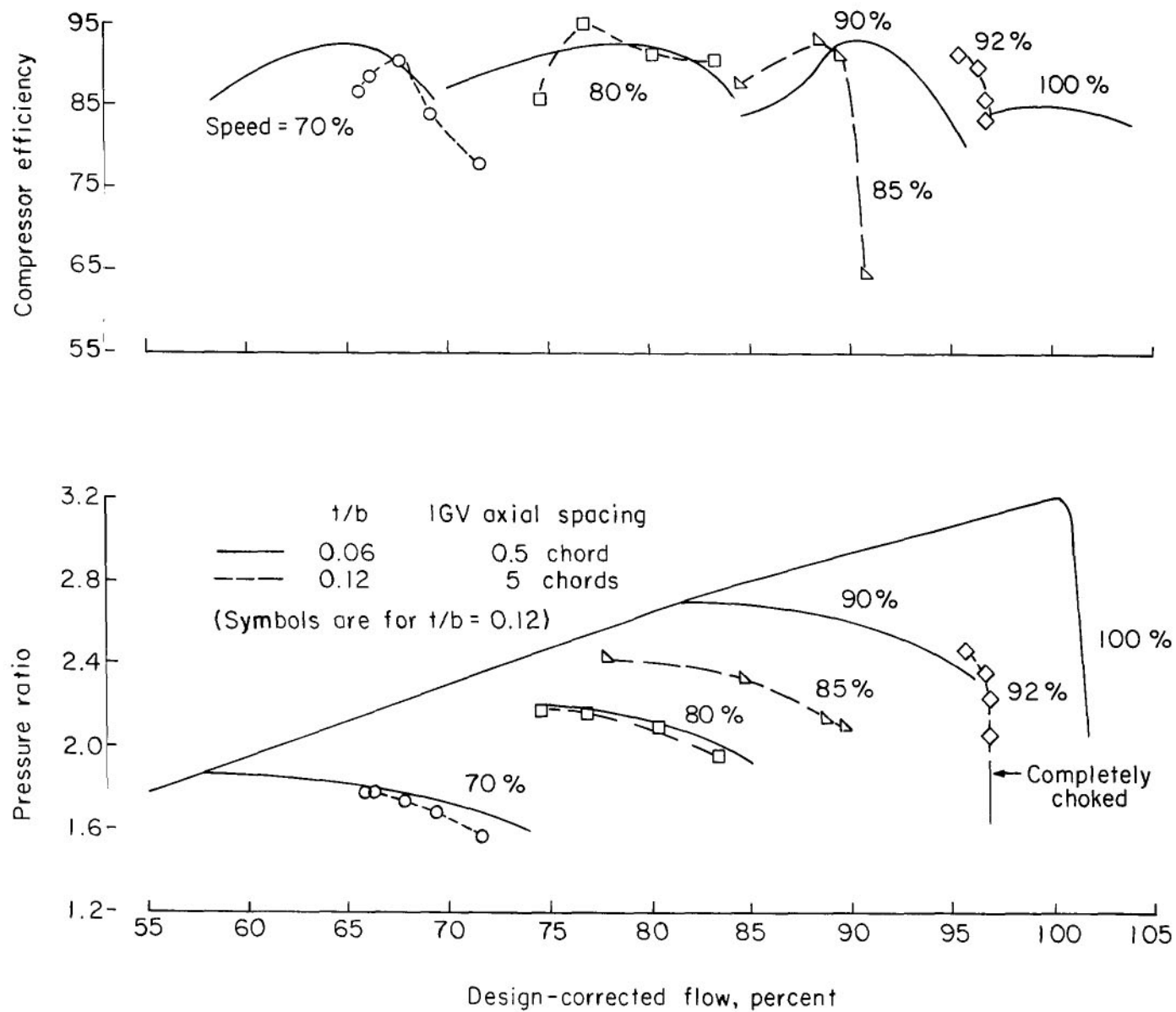
Figure 7.- Compressor performance curves for three-stage transonic compressor with 0⁰ inlet-guide-vane setting.
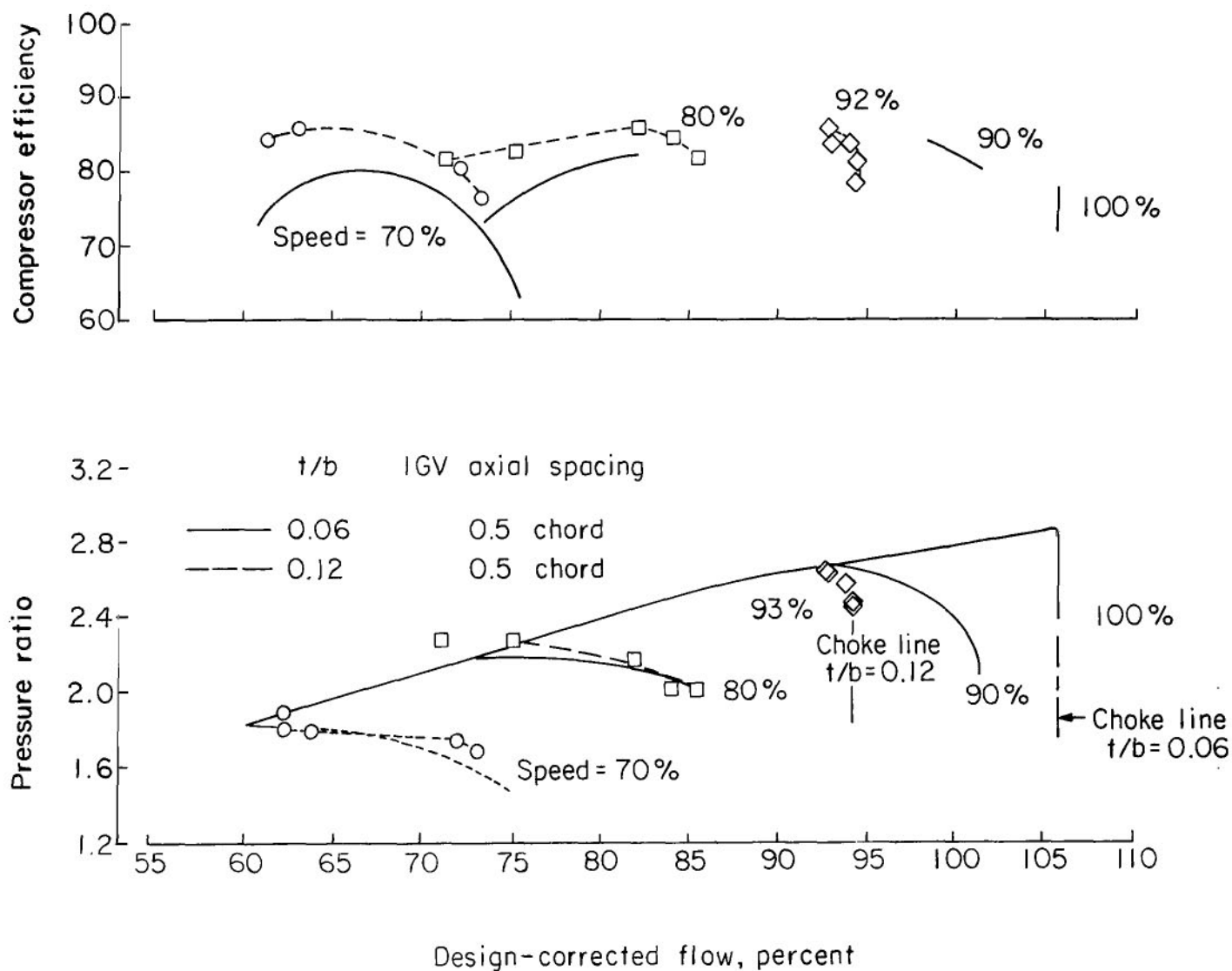
Figure 8.- Compressor performance curves for three-stage transonic compressor with 15⁰ inlet-guide-vane setting.

(a) 70-percent design speed.
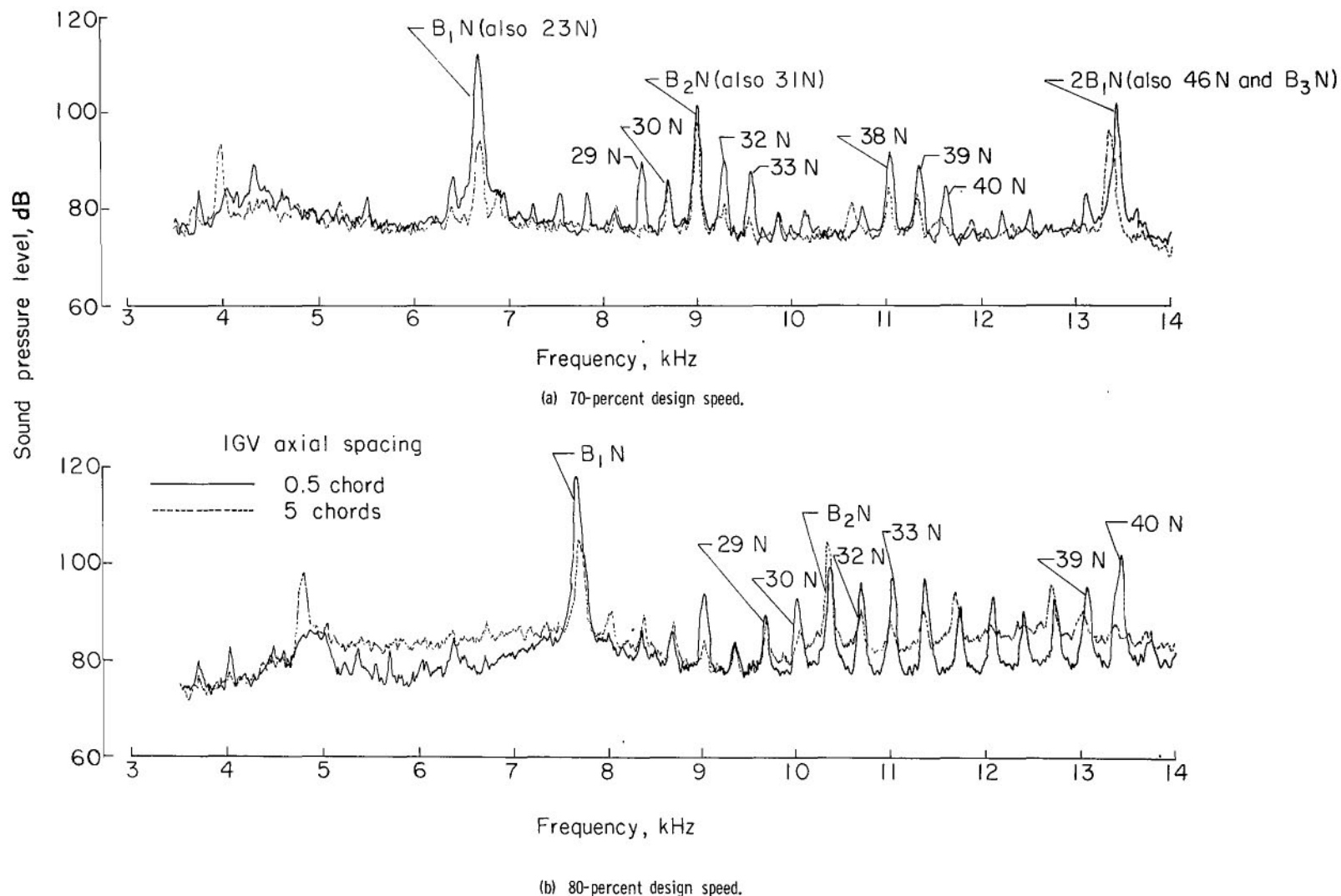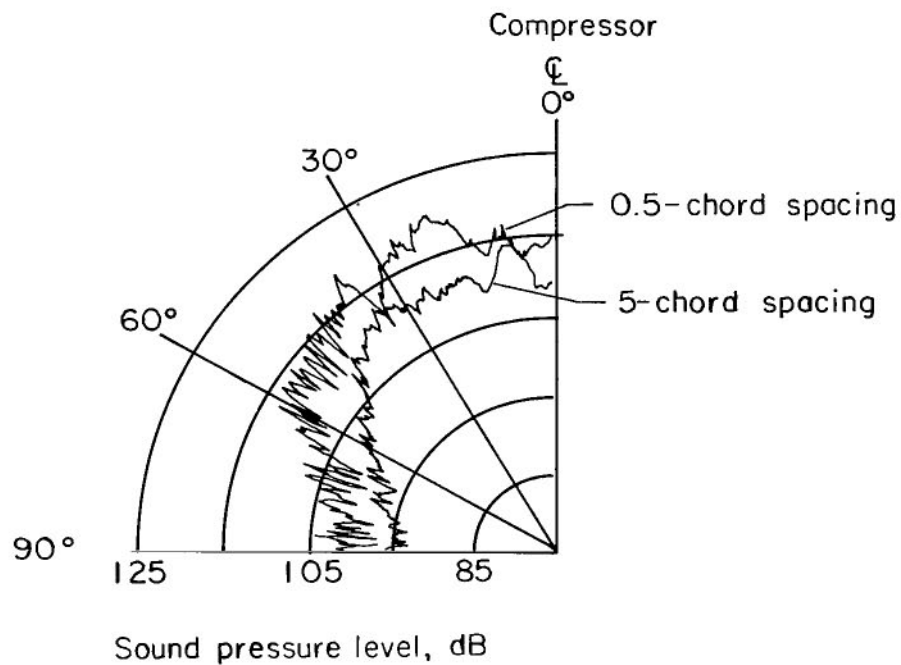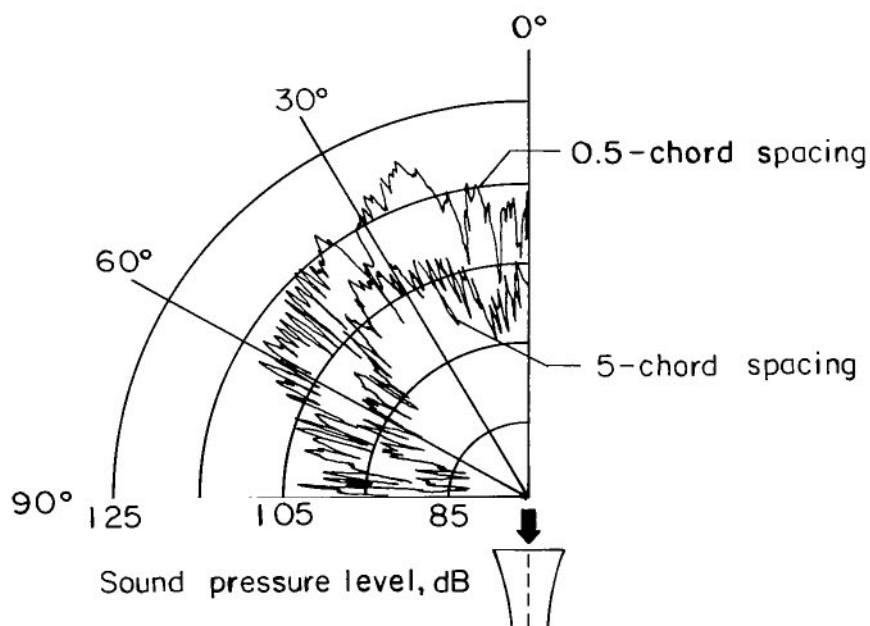
(b) 80-percent design speed.

Figure 9.- Comparison of frequency spectra for three-stage transonic compressor with 12-percent-thick inlet guide vanes at axial spacings of 0.5 and 5.0 chords. Data measured at 30° azimuth angle on 10-ft (3.05-m) radius; noise spectra obtained with 50-Hz constant-bandwidth filter.

Compressor

$\underline{\mathbb{C}}$
0°

30°

0.5-chord spacing

5-chord spacing

60°

90°

125   105   85

Sound pressure level, dB

(a) Overall noise.

0°

30°

0.5-chord spacing

60°

5-chord spacing

90° 125   105   85

Sound pressure level, dB

(b) First-blade-passage-frequency noise.

Figure 10.- Effects of 12-percent-thick inlet-guide-vane spacing in transonic compressor on noise radiation patterns at 70-percent design rpm.

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— NATIONAL AERONAUTICS AND SPACE ACT OF 1958

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