

21. POTENTIAL OF INLET-GUIDE-VANE CONFIGURATION FOR INLET NOISE REDUCTION

By David Chestnutt and John L. Crigler
NASA Langley Research Center

SUMMARY

The effects of inlet guide vanes on the noise radiated from the inlet of an axial flow compressor are discussed. It is found that an inlet-guide-vane—rotor spacing of 2 to 3 chords appears to be an optimum configuration. It is shown that inlet guide vanes can be used to aerodynamically choke the flow to produce a sonic barrier to inlet noise radiation. This sonic barrier has reduced the inlet noise up to 30 dB and has been obtained over virtually the entire operating range of the test compressor. In addition, inlet noise reduction is shown to be a function of average Mach number between guide vanes above Mach 0.65. Performance losses during choked-flow operation are shown to be modest.

INTRODUCTION

Recent research has indicated that inlet guide vanes can favorably reduce the radiation of noise from the inlet of a compressor. The role of inlet guide vanes (IGV) in the alleviation of inlet noise is presented schematically in figure 1. Shown in this figure is a turbofan engine which emits noise from three major sources: namely, the primary jet, the fan discharge, and the inlet. The inlet noise and fan discharge noise are made up mainly of broadband and discrete tones radiating from the rotating machinery. Inlet guide vanes may be axially spaced to control the strengths of the wakes encountered by the rotor (illustrated in the sketch at the lower left in fig. 1). The effects of such wake interactions on the compressor noise are included in reference 1. Inlet guide vanes may also be used for locally choking the inlet flow (illustrated in the sketch at the lower right in fig. 1). Both the wake-interaction and the choked-flow phenomena are discussed from the standpoint of their effect on noise reduction.

INLET-GUIDE-VANE—ROTOR SPACING

The effects of aerodynamic interactions on the noise of a turbojet engine are shown in figure 2. Observe the differences in 1/3-octave band sound-pressure-level (SPL) spectra for 30° azimuth in front of the engine with inlet guide vanes (IGV) at two different axial spacings. The solid-line record represents a noise spectrum for a spacing of 1/8 chord; the dash-line record represents a spectrum for a spacing of 6 chords. It can be seen that

there are significant noise reductions at all band center frequencies. These noise reductions result apparently from reduced aerodynamic interaction effects due to increased inlet-guide-vane—rotor spacing.

A summary of all available data (refs. 2 to 8) related to the effects on noise of inlet-guide-vane—rotor spacing is presented in figure 3. Included are data for the fundamental-blade-passage frequencies from engines as well as those from single-stage subsonic compressors and from multistage transonic compressors. All noise levels are referred to those at an axial spacing of 0.125 chord. As axial spacing is increased, the relative noise levels generally decrease. These effects of spacing are greater for small axial spacings, where potential flow effects as well as strong wake interactions may be present, and become less at the larger axial spacings. The noise reductions obtainable for large IGV-rotor spacings approach those resulting from total removal of the inlet guide vanes. An inlet-guide-vane—rotor spacing of 2 to 3 chords appears to be an optimum configuration.

INLET-GUIDE-VANE CHOKING

Test Arrangement

All inlet-guide-vane choking studies at the Langley Research Center were made with a three-stage transonic axial-flow air compressor (fig. 4). This photograph was taken during the installation phase and shows the bellmouth inlet and downstream diffuser. The inlet noise from this compressor radiated into an anechoic chamber in which far-field measurements were taken. The compressor embodying current compressor design technology can operate as a one-, two-, or three-stage machine. Provision is made for changing the number of rotor blades and stator vanes. The three-stage transonic configuration was used in this investigation. The compressor is driven by a 3000-hp variable-speed electric motor and has a maximum design speed of 25 000 rpm.

Figure 5 presents the performance curves for this three-stage transonic compressor. Both the efficiency and pressure-ratio curves are fairly typical of those for transonic compressors. Note especially the flat pressure-ratio curves in the subsonic region and the nearly vertical curve denoting transonic operation. Whenever noise data were collected for this compressor, corresponding compressor performance data were also taken. During this investigation the compressor was operated over the range of pressure ratio and at the rotational speeds indicated. Further details regarding this equipment are given in reference 3.

Effects of Mach Number Between Inlet Guide Vanes

Figure 6 shows the relative overall sound pressure level as a function of average axial Mach number M_{av} between adjacent inlet guide vanes. This relationship was

originally presented in reference 3 for choking obtained either by turning the inlet guide vanes in a direction opposed to rotor rotation or by thickening the inlet guide vanes. The data of figure 6 are representative of either method for obtaining choking. In reference 9, choking in the compressor inlet was effected by a variable cowl. Aerodynamic choking is defined as a condition at which the air velocity has reached the acoustic velocity and no sound can be propagated upstream through the choked region. At an average Mach number of about 0.65, there begins a gradual reduction in noise level as the Mach number is increased. At an average Mach number of approximately 1.00 where the full effect of choking is realized, there is a dramatic reduction in the noise level. The measured noise reduction of 30 dB shown was obtained from a compressor configuration with IGV-rotor spacing of 1/2 chord. Had the spacing been less, the noise reduction would have been correspondingly greater because of the higher initial noise level.

Far-Field Radiation Patterns and Spectra

In figure 7 are seen the far-field radiation patterns for both choked and unchoked flow conditions. These patterns were obtained by using a traversing microphone spaced 10 inlet diameters from the compressor inlet. The outer pattern represents a typical unchoked condition with an inlet-guide-vane—rotor spacing of 1/2 chord and shows a marked variation in the noise level. The inner pattern represents a typical choked condition for which inlet-guide-vane—rotor spacing is not believed significant, the noise levels are lower, and there is less noise variation with azimuth. The corresponding spectra for these patterns are shown for comparison in figure 8. The upper 1/10-octave spectrum was taken at 30° azimuth and is representative of the unchoked condition. The lower 1/10-octave spectrum was taken at the same azimuthal value and is representative of the choked condition. The two important observations to be made are that as a result of choking, the sound pressure level has been reduced considerably across the entire spectrum and the peaks at the fundamental-blade-passage frequency and its harmonics have been eliminated. Because of the higher rotational speed mentioned previously, the fundamental-blade-passage frequency is higher than that encountered in larger slower rotating compressors.

Effects of Compressor Speed

The relative merits of retaining inlet guide vanes to effect choking, yet spacing them properly for minimum interaction noise when the compressor is operating in an unchoked mode, are established by the data in figure 9. The inlet guide vanes used in this figure were designed for choking at a compressor speed of 100 percent design corrected speed (rpm). An inlet configuration with an IGV-rotor spacing of 1/2 chord is represented by the dash-line curve with square symbols. As the compressor speed is increased from 70 percent to 100 percent rpm, there is a sharp reduction in the noise level and the inlet

is aerodynamically choked. The dash-line curve with circular symbols represents an inlet configuration with no inlet guide vanes and for which the noise levels are decidedly lower at 70 percent rpm but, as the compressor speed is increased, there is only a relatively small additional noise reduction. The obvious compromise is to space properly the inlet guide vanes to minimize the aerodynamic interactions when the compressor is operating in an unchoked mode. This configuration is represented by the solid-line curve. As the compressor speed is increased for this configuration, the same minimum noise level is obtained at 100 percent rpm as with the configuration with 1/2-chord IGV-rotor spacing. Therefore, variable-geometry inlet guide vanes with appropriate axial spacing would produce relatively lower interaction noise levels and could provide substantial noise reductions by means of flow choking.

The experimental work accomplished to date with the three-stage transonic research compressor is shown in figure 10. The hatched area at the top of the figure indicates the noise reductions available at the fundamental-blade-passage frequency by increased axial spacing. A reduction in noise of approximately 10 dB was obtained with increased IGV-rotor spacing to the point of removal of the inlet guide vanes. A combination of increased IGV-rotor spacing and choking by means of increased IGV turning provided an additional 20-dB noise reduction which has been obtained at compressor speeds from approximately 72 percent rpm to 100 percent rpm.

Compressor Performance

Some consideration should be given to the effect of choking on compressor performance. The experimental data presented in table I provide a partial answer to this effect and show that performance is a function of how choking is obtained. Choking has been obtained by thickening the inlet guide vanes, by turning the inlet guide vanes, or by a combination of thickening and turning. Compressor efficiency losses of 4 to 5 percent and pressure-ratio losses of 4 to 10 percent were measured during choked-flow operation, and an increase in surge sensitivity was observed.

Although the adverse performance results indicated in table I are known to be critical for full-power operation, they may not be critical for off-design operation, such as might occur during an airplane second-segment climb or landing approach for which noise reduction is an important consideration. If a choked-flow inlet is incorporated in the initial compressor design, it is believed that the performance penalties noted in the table could be minimized.

CONCLUDING REMARKS

The results of this study suggest that variable-geometry inlet guide vanes with appropriate inlet-guide-vane—rotor spacing can provide large inlet noise reductions.

Such a design concept seems to be worthy of consideration for reducing noise of future axial-flow compressors even though some additional mechanical complexity may be involved.

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TABLE I.- EFFECTS OF CHOKING ON COMPRESSOR PERFORMANCE

Means of choking	Comparison with unchoked operation		
	Surge sensitivity	Efficiency loss, percent	Pressure-ratio loss, percent
IGV thickening	Increased slightly	-----	8 to 9
IGV turning	Increased	4 to 5	8 to 10
IGV turning and thickening	Increased slightly	-----	4 to 5

ROLE OF INLET GUIDE VANES

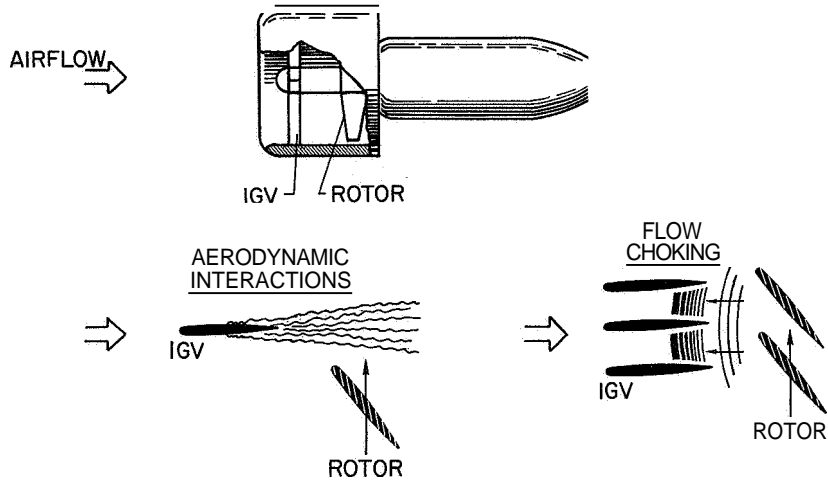


Figure 1

EFFECTS OF INLET-GUIDE-VANE—ROTOR SPACING TURBOJET ENGINE

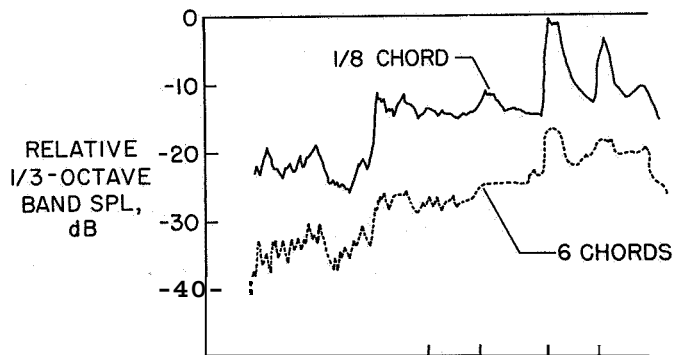


Figure 2

SUMMARY OF IGV-ROTOR SPACING EFFECTS ON NOISE

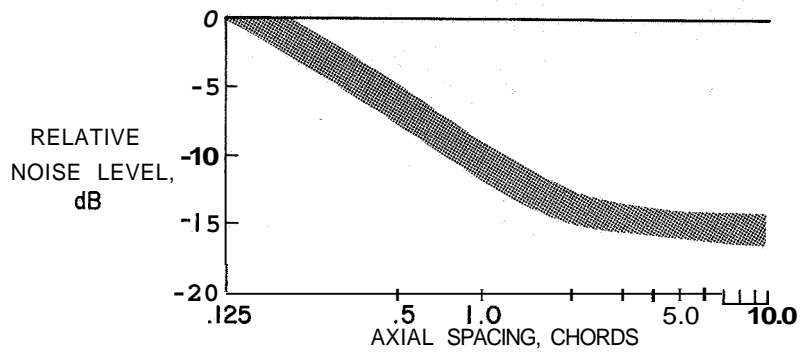


Figure 3

TEST ARRANGEMENT

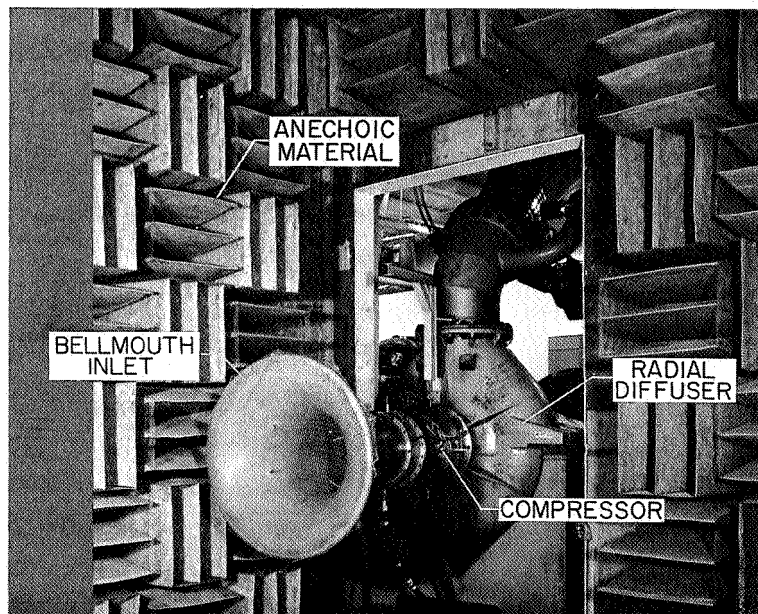


Figure 4

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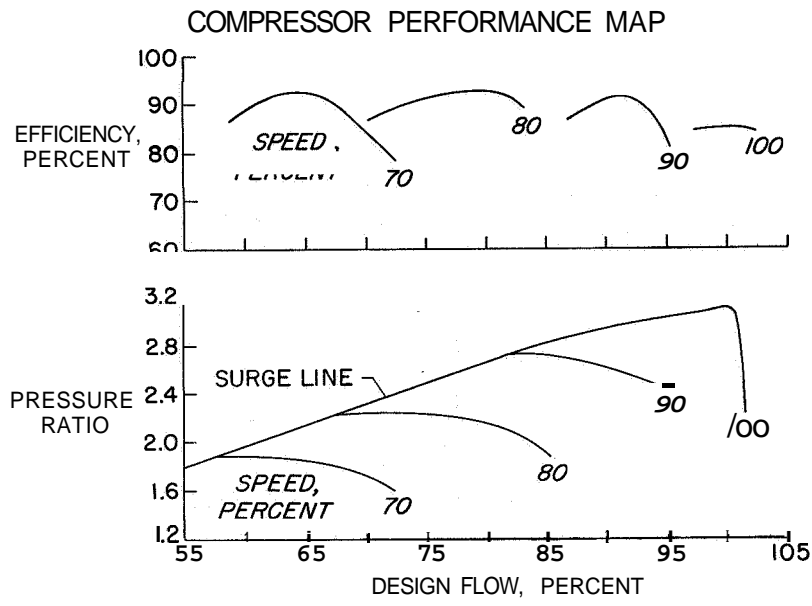


Figure 5

EFFECTS OF MACH NUMBER BETWEEN INLET GUIDE VANES

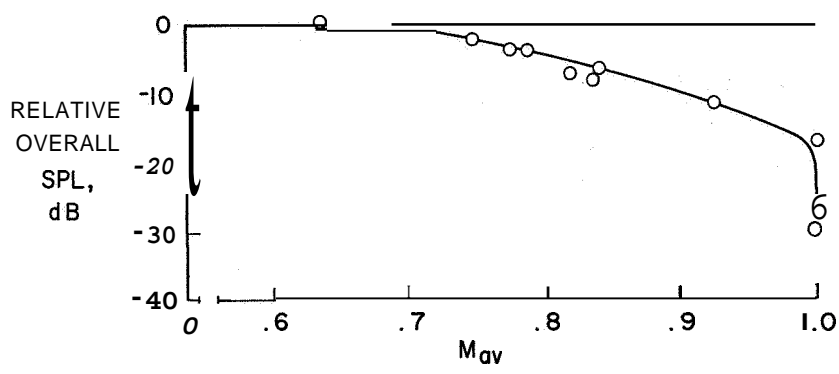


Figure 6

FAR-FIELD RADIATION PATTERNS
 AXIAL SPACING = 0.5 CHORD

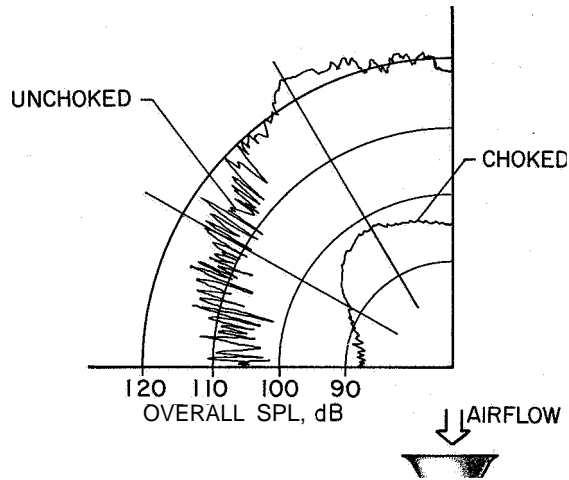


Figure 7

FAR-FIELD SPECTRA
 AZIMUTH = 30°

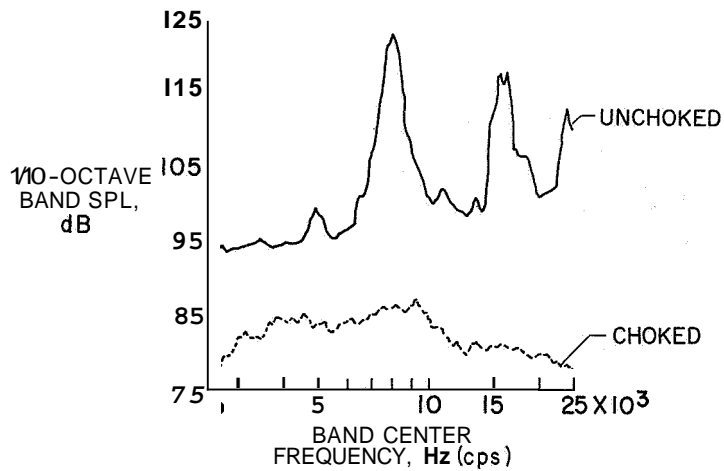


Figure 8

EFFECTS OF COMPRESSOR SPEED

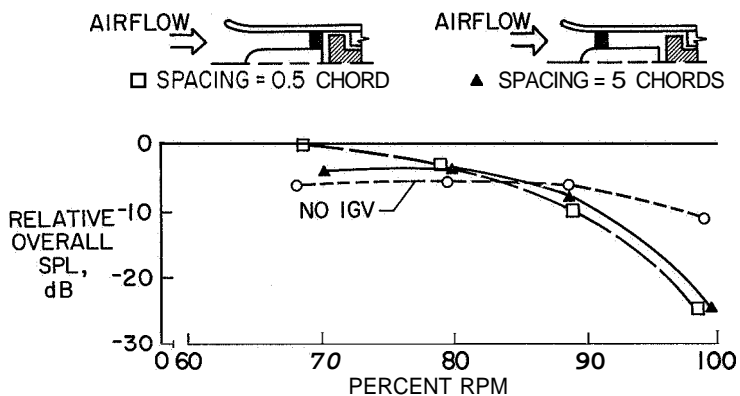


Figure 9

NOISE REDUCTION INVOLVING INLET GUIDE VANES

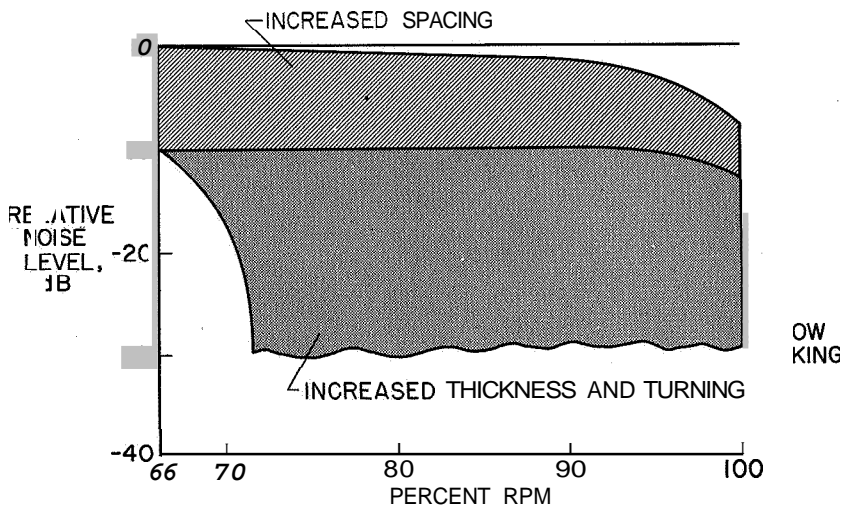


Figure 10