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## SONIC INLET NOISE ATTENUATION AND PERFORMANCE WITH A J-85 TURBOJET ENGINE AS A NOISE SOURCE

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Abstract

A static test program was conducted at the Lewis Research Center to investigate aerodynamic and acoustic performance of a sonic inlet used as a noise suppressor. A translating centerbody type inlet with radial vanes was tested ahead of a J85-GE-13 turbojet engine. The inlet when fully choked, maintained high recovery with low distortions while dramatically reducing noise emanating from the compressor. Recoveries of 98.1% at simulated takeoff and 95% at approach were attained with associated sound attenuations of 40 db and 38 db respectively. Inlet lip shape was found to have significant effects on noise attenuation at these static conditions.

## Introduction

In order to meet noise requirements, future aircraft now being planned must utilize suppression devices both on the jet exhaust and on the fan noise. A method of suppressing fan noise that has been investigated is choking the inlet flow. For the past ten years many investigations have been conducted on sonic inlet technology. An excellent summary of this past work is presented in reference 1. This reference cites sixteen experimental programs that were conducted on full scale engines, scaled models, and with various devices used as noise sources. As pointed out in this reference, due to variations in configurations and test and measurement techniques, the resulting scatter in the data is sufficiently large to preclude specific conclusions. However the trend shown was that sonic inlets did offer promise in noise reduction. Other current work on sonic inlet designs is reported in reference 2.

To further investigate sonic inlets which would have application for future aircraft, such as near-sonic, advanced supersonic, or STOL transports, the Lewis Research Center undertook a program to test a variety of inlets which had such future applications. These included axisymmetric and two-dimensional inlets for supersonic application, and translating centerbody inlets with radial vanes for near-sonic or STOL type aircraft. The purpose of this program was to evaluate both the aerodynamic and acoustic performance of these inlets at static conditions with a J85-GE-13 turbojet engine as a noise source. The purpose of this paper is to present the test results of the translating centerbody, radial vane inlet.

## Symbols

$D_{hi}$ cowl highlight diameter

$D_{th}$ cowl throat diameter

Dist distortion, maximum compressor face total pressure minus minimum ratioed to $\bar{P}_2$

h distance of pressure probe from hub

$M_0$ flight Mach number

$M_{TH}$ inlet throat Mach number

OASPL overall sound pressure level, db

PNdb percieved noise level, db

$\bar{P}_2$ average compressor face total pressure

$P_{RMS}$ root mean square of dynamic total pressure

R radial distance between hub and tip at rake measuring station

$\frac{W\sqrt{\theta}}{\delta}$ engine corrected weight flow

$\delta$ ratio of compressor face total pressure to standard sea level pressure

$\Delta$db reduction in 1/3-octave band sound pressure level, db

$\theta$ ratio of compressor face total temperature to standard day temperature

## Apparatus and Procedure

### Facility

The test assembly is shown in fig. 1. It was located adjacent to airport on the ramp at Lewis Research Center. The J85-GE-13 engine was enclosed in a flight type nacelle with engine cooling air supplied through lines attached to the side of the nacelle aft of the engine. To muffle the compressor noise, in order to initially determine the noise floor, a special inlet system was installed. Figure 2 is a schematic showing the overall system. The inlet muffler consisted of initial section lined with fiberglass matting, and turning vanes followed by a section of acoustic panels tuned to attenuate noise at blade passage frequency. A transition section was installed just ahead of the compressor with a throat sized for Mach 0.70 when the engine was at full speed. The exhaust muffler system consisted of two cylindrical sections lined with acoustic material and had screen inserted at three stations. In addition, the engine was operated with the primary nozzle locked fully open to reduce the velocity of the exhaust jet.

### Instrumentation and Recording

Acoustic data were obtained from 10 microphones, equipped with wind screens, arranged as shown on fig. 3. The microphones were spaced every 10° on a 9.14 meter (30 ft) radius from the compressor face. The microphones were 1.67 meters above the ground at the same height as the engine axis.

The microphone output was recorded on 14-track FM tape for subsequent data reduction. The microphone signals were amplified and sent to a 1/3 octave band spectrum analyzer with a digital output so that data could be monitored during a test.

Steady state pressures were obtained by a scani-valve and read out on a strip chart recorder in the control room. Dynamic total pressures at the compressor face were acquired by Kulite transducers and manually read out on RMS meters.

### Inlet Design

A sketch of the translating centerbody, radial vane inlet is shown in fig. 4. The inlet was equipped with a motor-driven centerbody for remote positioning. For the cruise condition the centerbody was retracted to give a throat Mach number of 0.70. At this condition the radial vanes were also retracted into the cowl. For takeoff the vanes remained retracted but the centerbody was translated forward to a position that gave an 8.65% area reduction from the cruise position. For the approach condition the centerbody was translated forward and the vanes were extended to provide a total area reduction of 34%.

The 36 radial vanes were of constant thickness from hub to tip and were NACA 63-010 airfoil sections. They were not remotely retractable for this test series.

The inlet design incorporated four different inlet lip configurations to study the effect of inlet entrance conditions on the aero-acoustic performance. A series of elliptical internal lips of major to minor axis ratios of 2:1, 3:1, and 4:1 were tested. All of these lips had contraction ratios of 1.32 $(D_{hi}/D_{th})^2$. In addition, a bellmouth was designed whose internal contour simulated the stagnation streamline of flight conditions at $M_0 = 0.30$ for takeoff and $M_0 = 0.20$ for approach. This streamline contour was analytically predicted using a potential flow program. Figure 5 shows the forward velocity bellmouth installed on the engine.

The inlet instrumentation is shown on fig. 6. Static pressure orifices were located longitudinally and circumferentially on the inner cowl surface and on the centerbody at the throat. Steady-state total pressures at the compressor face were measured by three area weighted rakes located 120° apart. Dynamic compressor face pressures were measured by four Kulite transducers installed in a rake mounted just ahead of the compressor.

### Procedures

Initial engine runs were made with an elliptical bellmouth on the front of the engine and with the exhaust muffler on the aft portion to determine the reference level of the unsuppressed, J-85 compressor noise. The secondary objective of these runs was to obtain an engine airflow calibration so that inlet throat Mach number could be calculated using the corrected weight flow at the compressor face.

The sound and airflow calibrations were made by varying engine power setting, in one-percent increments, from 80 percent to 100 percent engine speed. At each data point power was stabilized and both sound and airflow data were recorded.

The second series of runs were made with the inlet muffler. The objective was to determine the noise floor. By comparing the spectral distribution of the reference noise with that obtained with the inlet noise muffled, the contribution of jet noise and machinery and background noise could be determined. This procedure was necessary to insure that noise attenuation levels, when the inlets were choked, could be accurately determined. The comparison also allowed for calculations of overall sound pressure level (OASPL) and perceived noise level in decibels (PNdb) to be made without including jet noise that was present in the spectral distributions. This was accomplished by using the following technique. Inspection of the spectral distributions of the reference level noise and the muffled inlet noise, to be presented later in the results section, showed that compressor noise was present in the spectrum as low as 250 Hz. This fact was determined because only frequencies above 250 Hz could be attenuated by muffling the compressor noise. Between 250 and 630 hertz, reference level noise could only be slightly attenuated therefore it was assumed that in this frequency band this noise was due primarily to jet exhaust. Above 630 hertz all choked inlet data, except the 2:1 lip, was above the noise floor determined with the inlet muffled. Therefore the logarithmic summations to calculate OASPL and PNdb levels were begun at 630 hertz and concluded at 10 K hertz.

Research runs were made on all configurations by varying engine speed between 90 and 100% for the takeoff conditions and between 80 and 90% for the approach conditions. The objective was to obtain aero-acoustic data over a range of throat Mach numbers. All data were taken after stabilized engine speed conditions had been reached.

For all testing, data taking was limited to ground wind velocities below 10 knots.

## Results

### Calibration Results

The results of the noise calibration with the exhaust muffler and inlet muffler are shown in fig. 7. The 1/3-octave-band spectral curve labeled reference noise was obtained with the exhaust muffler installed and with a plain bellmouth on the inlet. The curve labeled inlet muffler noise floor was obtained with the exhaust muffler and the inlet muffler. The data was obtained at 100% engine speed and is shown for the 50° microphone position. The noise calibration showed that a 40 db reduction in noise could be measured at the blade passage frequency of 8500 hertz. It also showed that compressor noise was present in the reference spectrum as low as 250 hertz. This was shown by the fact that reduction from the reference level with inlet noise muffled first occurred at 250 hertz.

### Aerodynamic Results

Figure 8 typifies the classical relationship of compressor face recovery and throat Mach number (engine speed). The data shown are for the 2:1 lip, and are for the takeoff configuration, but the data are typical of all conditions tested. As the throat Mach number was increased by increasing engine speed, the recovery decreased and the steady state distortion increased. At 90% speed where throat Mach number was approximately 0.70, the recovery was 0.987 and the distortion was only 2.8%. At 100% speed and supercritical conditions the recovery dropped to 0.957 and the steady-state distortion was 11.57%. However the inlet was choked at about 94% engine speed where the recovery was still at 0.981 and distortion was 5.28%. This speed was selected as the choked condition because the corrected weight flow had reached 99.7% of that required to choke and also because further increases in engine speed gave no further increases in noise attenuation. The profiles show that as speed was increased above that required for choking a larger and larger deficit of total pressure occurred near the hub. A summary of pressure recoveries and distortion values for all configurations will be presented in a following section which will summarize both aero and acoustic performance.

Local dynamic distortions for all configurations tested are shown on fig. 9. The root-mean-square (RMS) levels of distortion as a percentage of average compressor face total pressure $(P_{RMS}/\bar{P}_2) \times 100$ are plotted versus the radial location of the dynamic transducer. Figure 9(a) presents the RMS percentage levels for all lip configurations and the forward velocity bellmouth at the takeoff position of the centerbody and fully choked flow at 94% engine speed. Figure 9(b) presents similar data for the approach condition.

In general the dynamic distortion levels for the approach condition are lower than those for takeoff. The highest level for approach is 1.90% for the forward velocity bellmouth near the hub. At takeoff levels of 2.6% were exhibited by the 4:1 and 2:1 lips near the annulus midpoint and by the forward velocity bellmouth near the hub.

Acoustic Results

Third-octave-band noise spectra for the takeoff condition (approximately 94% engine speed) for all lip configurations are compared to the reference noise in fig. 10. The data presented were measured at the 50° microphone position. The reference noise peaked at the blade passage frequency (8500 hertz) at 108 db. Some interesting results occurred due to the differences in lip configurations. Both the 4:1 and 3:1 elliptical lips showed much less attenuation over the entire high frequency range than the 2:1 lip. Accompanied with this higher noise level was an intermittent high frequency screech on both the 3:1 and 4:1 lips. Broadband spectral analysis showed this screech to be the blade passage frequency. Similar results have been experienced in refs. 3 and 4. The 2:1 lip did not exhibit the screech and gave attenuations of the order that had been expected. As can be seen from fig. 10 the 2:1 lip gave sound levels that were at the noise floor of the facility which is indicated by the inlet muffler data points. Therefore absolute attenuations may be larger than could be measured at this test facility.

The forward velocity bellmouth gave results quite similar to the 2:1 lip. It cannot be positively concluded that the forward velocity bellmouth properly simulated the flow conditions that would be present in flight with forward velocity, but it is evident that flow conditions at the lip of the inlet have a significant effect on the noise attenuation.

The cause of the intermittent screech and limited attenuation was thought to be separation of flow at the inlet lip thereby providing a low velocity path through which the noise could propagate upstream. An analytical potential flow program was run to attempt to verify this theory. Figures 11 and 12 present the results of this investigation. The analytical cowl static pressures ratioed to ambient pressure are plotted versus the axial distance downstream from the cowl lip. At 2.03 cm (0.8 in.) from the lip highlight the measured static pressure was compared to the analytical values for a throat Mach number of 0.80, for the 4:1 and 2:1 lip configurations. Figure 11 shows the 4:1 lip results. The measured static pressure on the cowl lip was higher than predicted indicating a lower velocity and possible flow separation. This is also true for other downstream static taps on the 4:1 cowl. The same comparison for the 2:1 lip, fig. 12, showed that measured static pressures agreed quite well with analytical predictions and the flow was probably attached.

The above analysis was performed at a throat Mach number of only 0.80 because of limitations in the analytical program at higher throat Mach numbers, but the conclusions reached are valid because screech was present and low attenuations were measured on both the 3:1 and 4:1 lips at throat Mach numbers of 0.80.

Noise spectra for the approach condition are presented in fig. 13. Again, none of the configurations tested exhibited attenuations as low as the noise floor. The 3:1 and forward velocity bellmouth attenuations were about equal and the 4:1 attenuation was significantly lower.

It can be concluded from the above results that if static testing of sonic inlets produces a flow field at the inlet lip which causes separation on the lip, then attenuation levels cannot be accurately determined. Either the inlet must be tested with forward velocity or some type of bellmouth must be provided to preclude lip separation. Care must be taken to determine if lip separation is present during acoustic testing so that results are properly interpreted.

The directivity effects on attenuation levels at fully choked conditions are shown in fig. 14 for the forward velocity bellmouth at takeoff and approach. Similar results were obtained for the other lip configurations. The noise reduction at the blade passage frequency for takeoff and approach are presented as a function of angular location from the inlet centerline. These reductions were calculated as the difference between the reference noise level and the suppressed noise level at the same microphone location and at the same engine speed conditions. As can be seen the noise attenuation levels vary to a maximum of 6 db between maximum and minimum level throughout the quadrant. This spread was caused by the variation in reference noise level at each microphone location and by the fact that at some locations the attenuated level was at the noise floor. In general there appears to be no angle that provides significantly larger attenuation levels. The sound data presented throughout this paper were selected at the representative microphone position of 50°.

## Aero-Acoustic Interactions

The interaction between aerodynamic and acoustic performance is shown in fig. 15. The one-dimensional throat Mach number, steady-state recovery, and OASPL reduction is presented as a function of the percentage of design corrected weight flow to choke. The data are for the 2:1, 3:1 and 4:1 lips for the takeoff configuration of the centerbody. At the design corrected weight flow and throat Mach number of 1.0 the 2:1 lip exhibited the largest OASPL reduction of 30 db. At 93% of design corrected weight flow and a throat Mach number of only 0.70 the 2:1 lip gave a 15 db reduction. At this condition the 3:1 and 4:1 lips both gave a 10 db reduction. This would indicate that the lip configuration still had an influence at a throat Mach number as low as 0.70. All lips exhibited a trend of increased noise attenuation with increased throat Mach number, but over the range tested both the 3:1 and 4:1 lips gave lower attenuations.

The inlet total pressure recoveries of all three lip configurations for the takeoff condition were quite similar over the entire corrected weight flow range as shown on the recovery plot of fig. 15. The aerodynamic and acoustic performance is summarized in the following section.

## Performance Summary

The aero-acoustic performance for all lip configurations tested is summarized on figs. 16 and 17 for takeoff and approach respectively. For the takeoff condition, fig. 16, the fully choked recoveries ranged from 0.980 to 0.992 with the forward velocity bellmouth providing the highest recovery. Steady-state distortion levels were all acceptable with none exceeding 10%. The average dynamic distortion, which is the average RMS total pressure level of the four probes on the dynamic rake ratioed to average compressor face total pressure, did not exceed 1.3%.

The best acoustic performance was demonstrated by the 2:1 lip which gave 40 db attenuation at the blade passage frequency (8500 hertz), fig. 10. Calculated values of OASPL and PNdb reduction for the 2:1 lip were 30 and 26 db respectively. The forward velocity bellmouth gave about the same acoustic results as the 2:1 lip.

For the approach condition, fig. 17, all recoveries were about 0.950 and steady-state distortions were higher than for takeoff, but none exceeded 14%. The insertion of radial vanes at the throat may account for the higher distortion. The average dynamic distortions were lower for the 4:1 and 3:1 lips than at takeoff and the forward velocity bellmouth was slightly higher than takeoff with 1.5% average dynamic distortion. The acoustic performances of the 3:1 lip and the forward velocity bellmouth were identical with 37 db attenuation at blade passage frequency (7000 hertz), and OASPL and PNdb reductions of 33 and 32 db respectively. The 4:1 lip again did not attenuate as well as the 3:1 lip.

## Summary of Results

A static test program which investigated the aerodynamic and acoustic performance of a translating centerbody, radial-vane-type, sonic inlet to suppress noise gave the following results:

1. With the inlet fully choked, noise attenuations at the blade passage frequency were demonstrated to be 40 db at takeoff and 38 db at approach. At takeoff fully choked, 30 db overall sound pressure level reduction was demonstrated. A 15 db noise reduction was achieved with a throat Mach number as low as 0.70.

2. Lip shape had a significant effect on attenuation levels measured. The 2:1 elliptical lip provided attenuation down to the noise floor while the 3:1 and 4:1 lips were significantly poorer attenuators. Flow separation on the internal surface of the inlet lip caused noise to leak forward on the sharper lips.

3. Compressor face total pressure recoveries of 0.981 for takeoff and 0.950 at approach were demonstrated at the choked condition.

4. Steady-state and dynamic distortion levels were well within acceptable limits for all configurations tested. Steady-state distortion did not exceed 10% for takeoff nor 14% for approach. Dynamic distortion did not exceed an average of 1.3% for takeoff nor 1.5% for approach.

## References


1. Klujber, J.F., Bosch, J.C., Demetrick, R.W., and Robb, W.L., "Investigation of Noise Suppression by Sonic Inlets for Turbofan Engines. Volume 1: Program Summary," CR-121126, 1973, NASA pp. 206-207.

2. Compagnon, M.A., "A Study of Engine Variable Geometry Systems for an Advanced High Subsonic Long Range Commercial Aircraft," CR-134495, 1973, NASA.

3. Klujber, F., "Results of an Experimental Program for the Development of Sonic Inlets for Turbofan Engines," AIAA Paper 73-222, Washington, D.C., 1973.

4. Miller, A., and Abbott, J.M., "Aerodynamic and Acoustic Performance of Two Choked Flow Inlets Under Static Conditions," TM X-2629, Sept. 1972, NASA.

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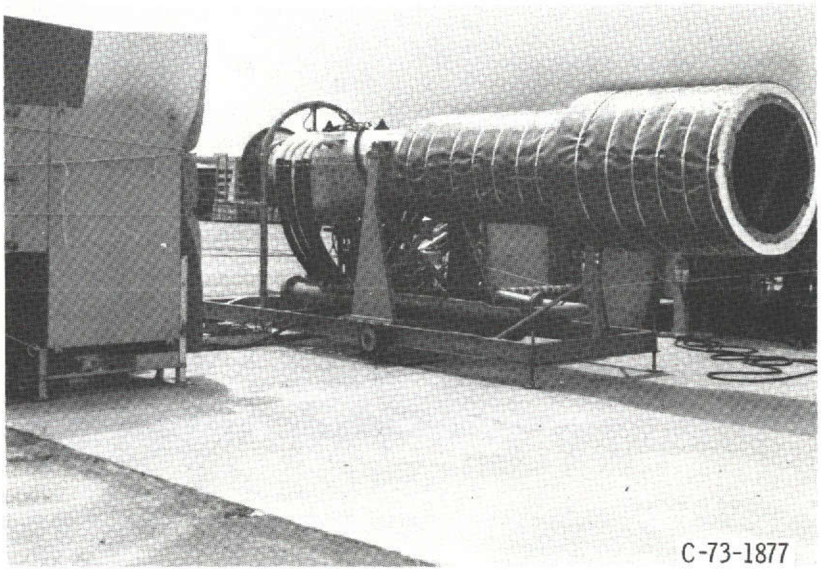


Figure 1. - Test facility.

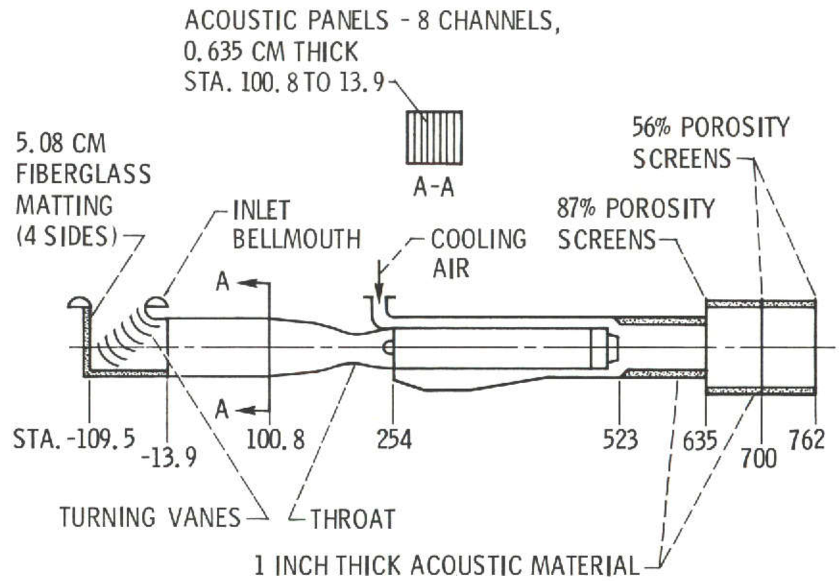


Figure 2. - Calibration inlet and muffler installed on J-85 engine-nacelle.

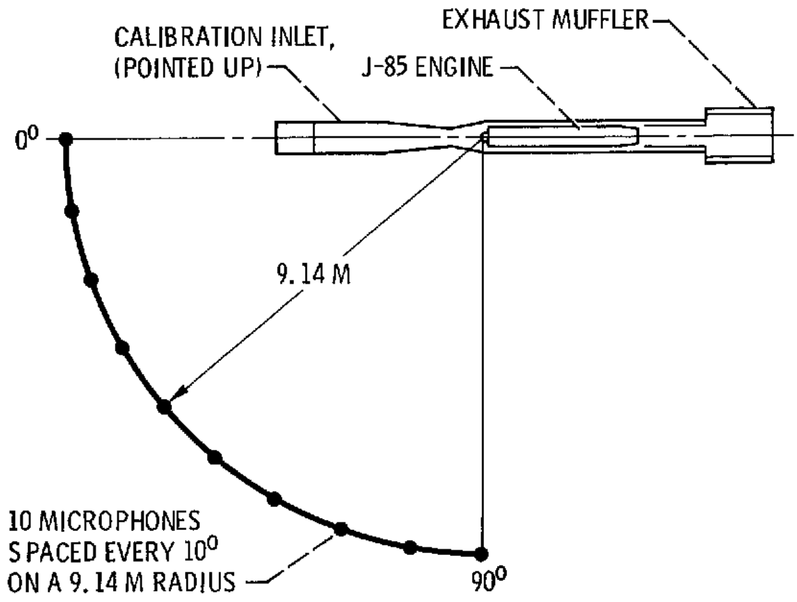


Figure 3. - Test set-up.

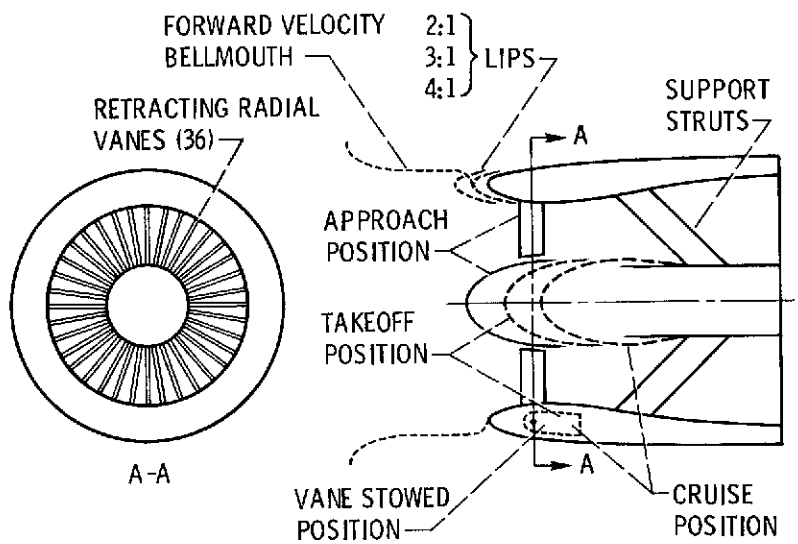


Figure 4. - Vane inlet configurations.

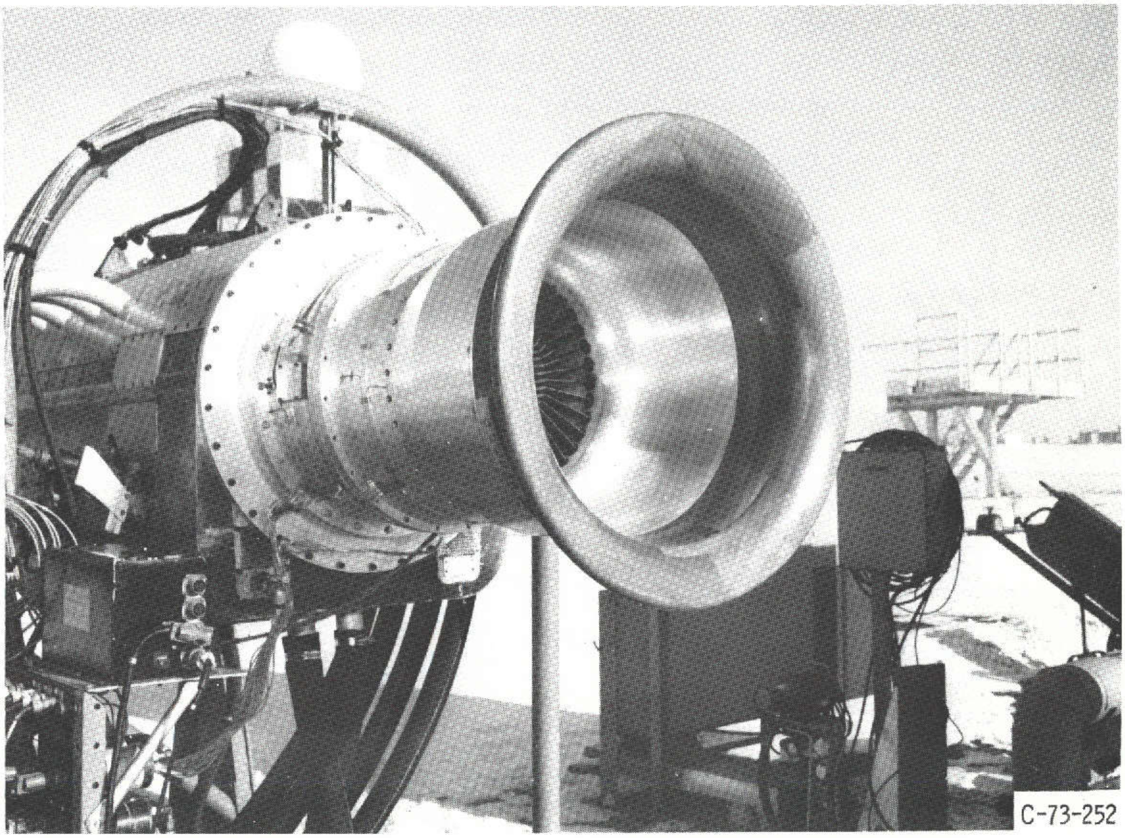


Figure 5. - Forward velocity bellmouth with radial vanes.

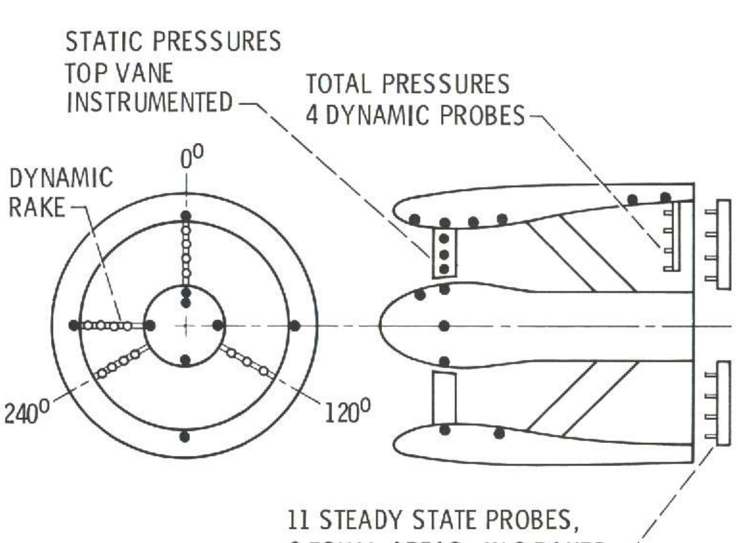


Figure 6. - Vane inlet instrumentation.



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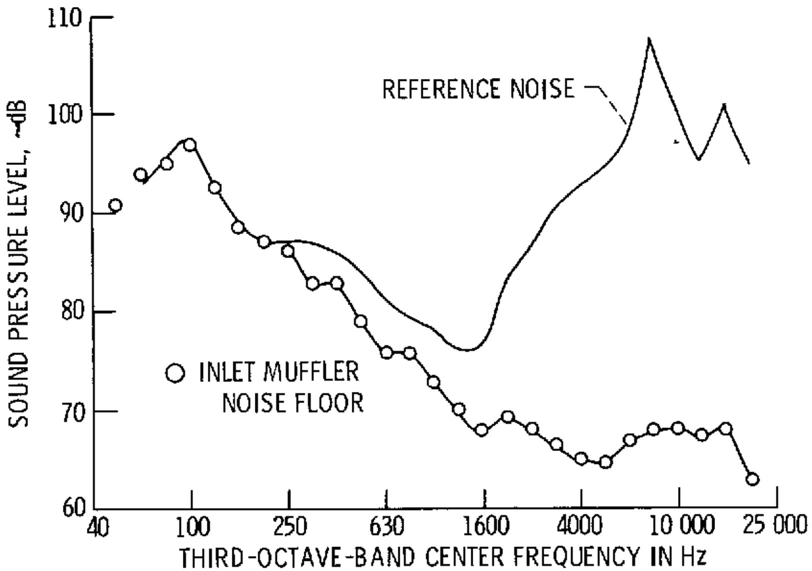


Figure 7. - Noise spectra of unsuppressed compressor noise and inlet muffled, 100 percent engine speed microphone at 50°.

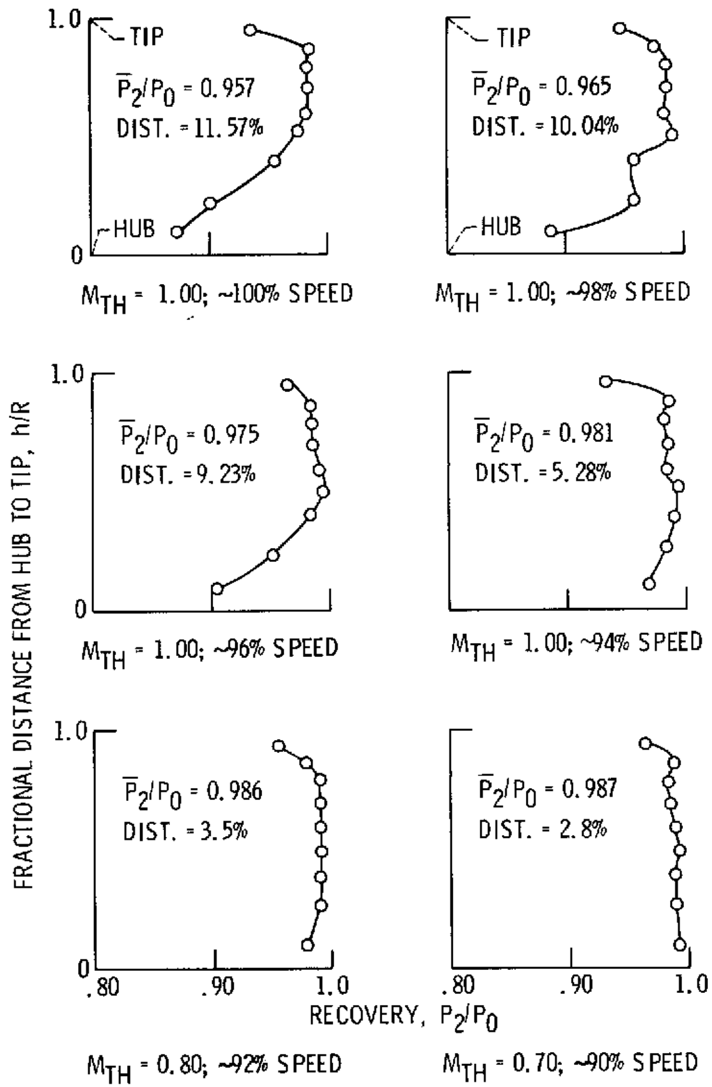


Figure 8. - Compressor face total pressure recovery profiles, 2:1 lip, takeoff condition.

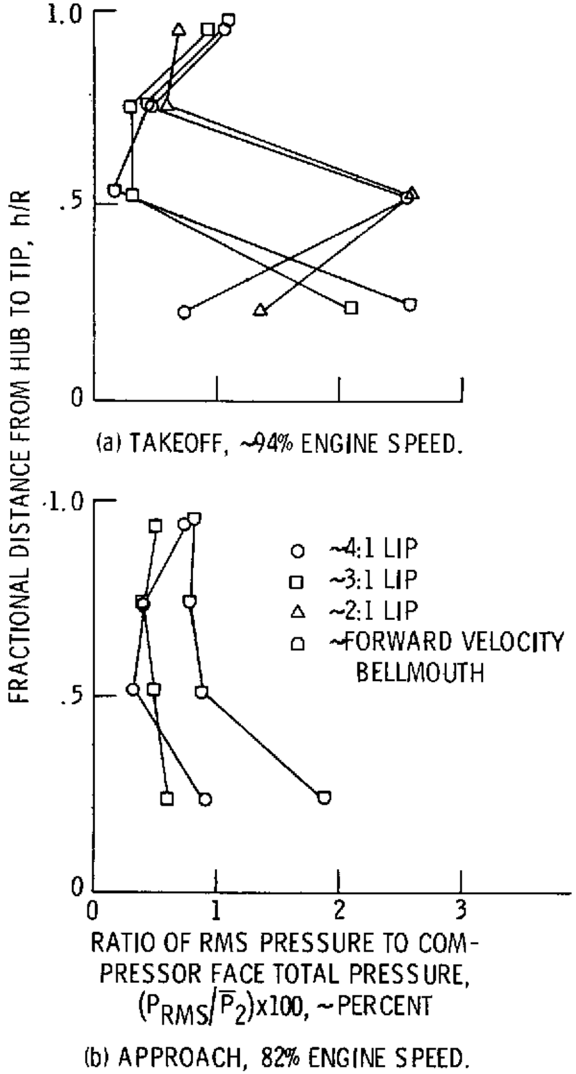


Figure 9. - Dynamic distortion profiles.

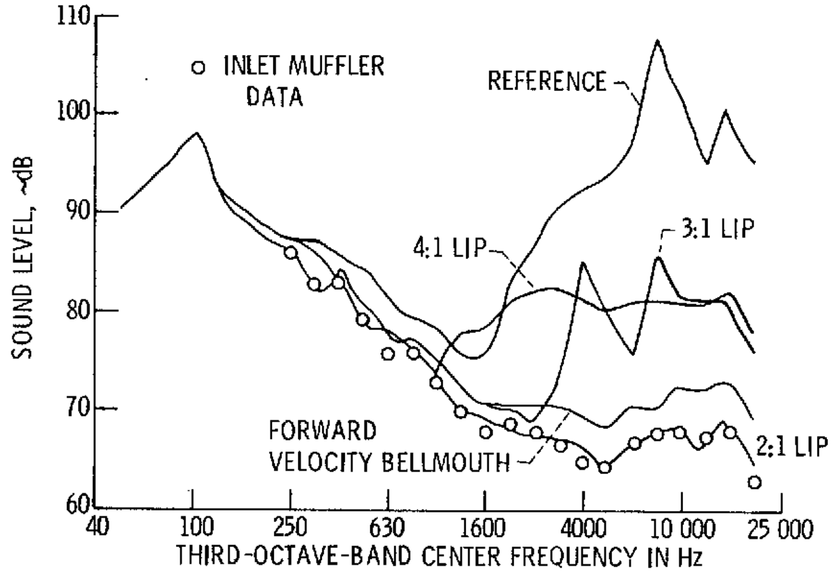


Figure 10. - Noise spectra of vane inlet with various lips takeoff condition, microphone position at 50°, fully choked, 94 percent engine speed.

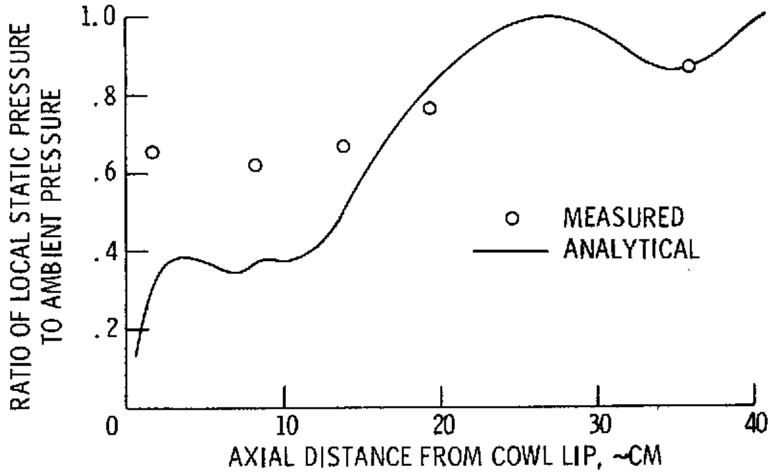


Figure 11. - Inlet internal cowl pressure distributions, 4:1 lip.

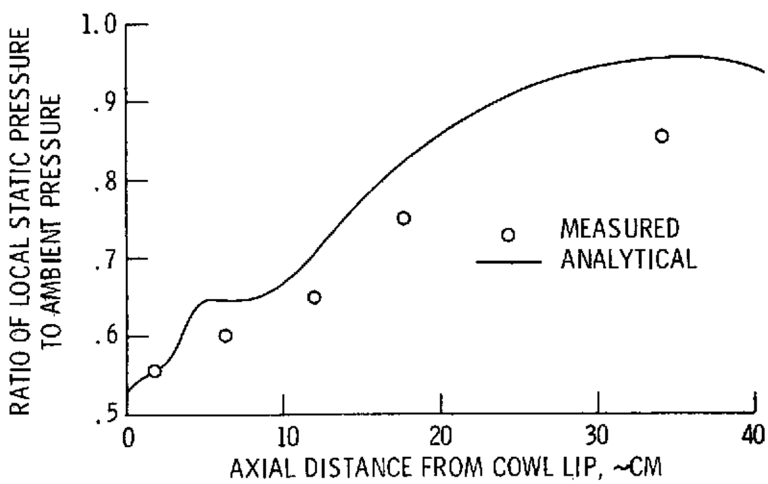


Figure 12. - Inlet internal cowl pressure distributions, 2:1 lip.

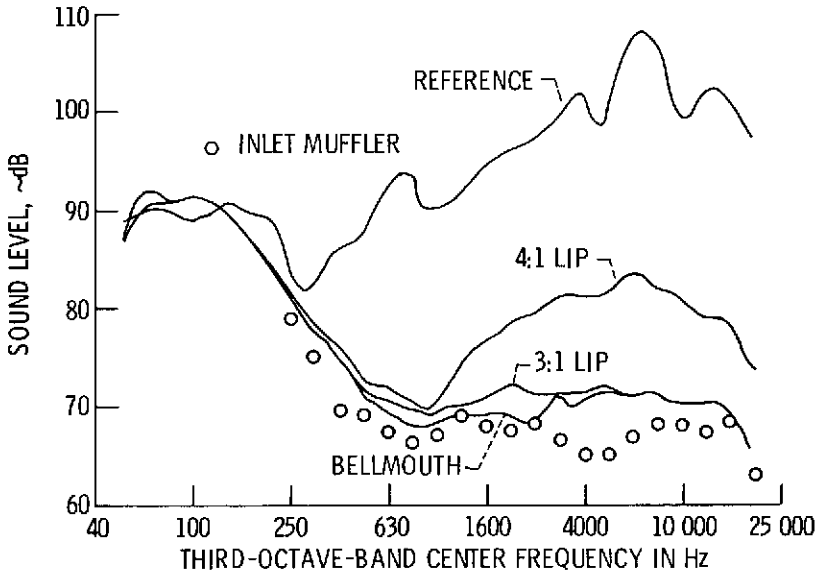


Figure 13. - Noise spectra of vane inlet with various lips approach condition, microphone position at 50° fully choked, 82 percent engine speed.

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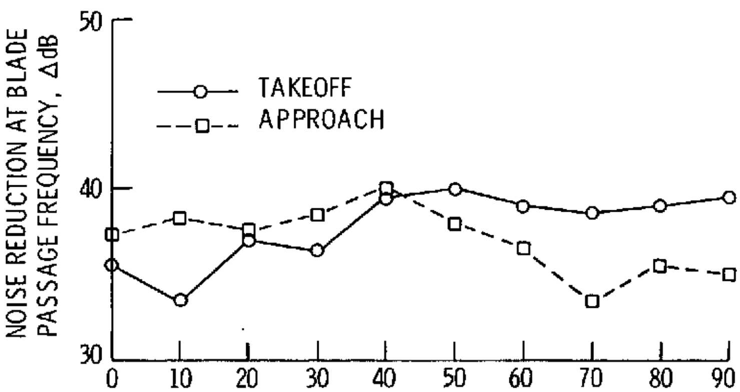


Figure 14. - Directivity effects on attenuation at blade passage frequency, forward velocity bellmouth, fully choked condition.

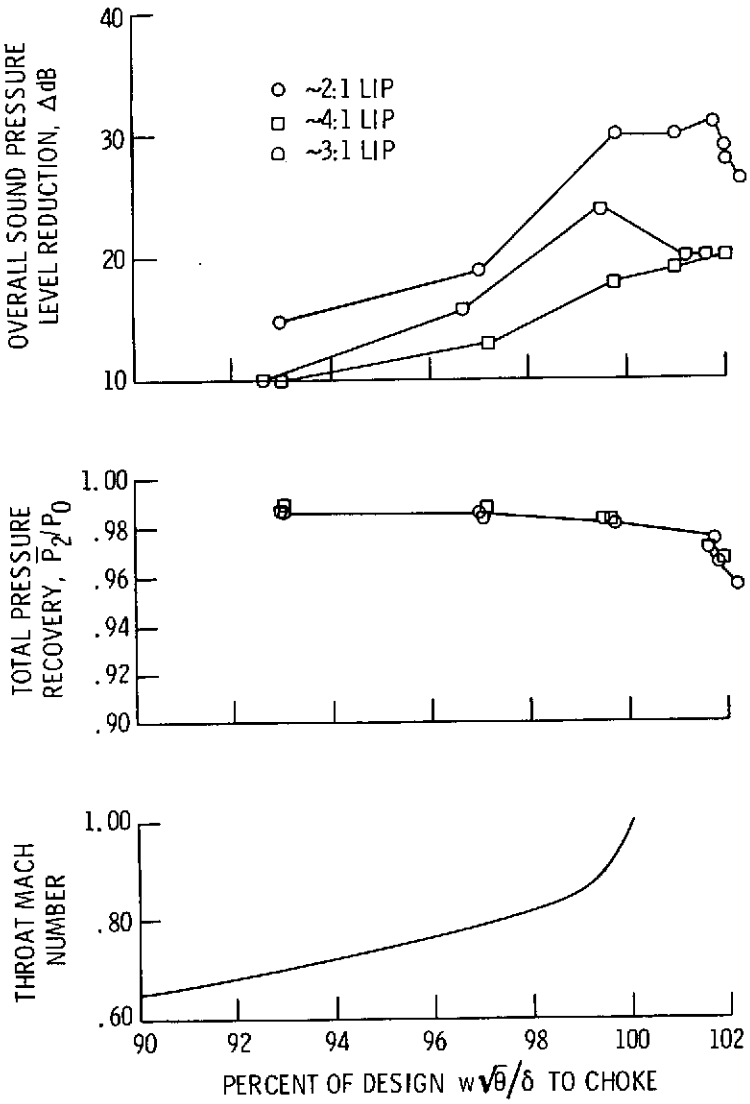


Figure 15. - Noise reduction, recovery, and one-dimensional throat Mach number versus percent corrected weight flow to choke for takeoff condition.

| INLET CONFIGURATION | RECOVERY | STEADY-STATE DISTORTION, % | DYNAMIC DISTORTION, $\overline{P}_{RMS}/\overline{P}_2$, % | OVERALL SPL ATTENUATION, dB | ATTENUATION AT BLADE PASSAGE FREQUENCY, dB | PNdB ATTENUATION, dB |
|---|---|---|---|---|---|---|
| 2:1 LIP | 0.980 | 5.28 | 1.3 | -30 | -40 | -26 |
| 3:1 LIP | 0.985 | 6.44 | 0.93 | -24 | -22 | -19 |
| 4:1 LIP | 0.987 | 9.80 | 1.2 | -18 | -27 | -16 |
| FORWARD VELOCITY BELLMOUTH | 0.992 | 7.67 | 1.0 | -28 | -40 | -26 |

Figure 16. - Performance characteristics, takeoff condition, fully choked.

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| INLET CONFIGURATION | RECOVERY | STEADY-STATE DISTORTION, % | DYNAMIC DISTORTION, $\overline{P}_{RMS}$ $\overline{P}_2$, % | OVERALL SPL ATTENUATION, dB | ΔdB AT BLADE PASSAGE FREQUENCY, dB | PNdB ATTENUATION, dB |
|---|---|---|---|---|---|---|
| 3:1 LIP | 0.958 | 9.46 | 0.50 | -33 | -37 | -32 |
| 4:1 | 0.949 | 11.71 | 0.80 | -25 | -25 | -21 |
| FORWARD VELOCITY BELLMOUTH | 0.946 | 13.92 | 1.50 | -33 | -37 | -32 |

Figure 17. - Performance characteristics, approach condition, fully choked.



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