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# Acoustic Characteristics of Two Hybrid Inlets at Forward Speed

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**A wind tunnel investigation of the acoustic and aerodynamic characteristics of two hybrid inlets installed on a JT15D-1 turbofan engine was performed. The hybrid inlets combined moderate throat Mach number and wall acoustic treatment to suppress the fan inlet noise. Acoustic and aerodynamic data were recorded over a range of flight and engine operating conditions. In a simulated flight environment, the hybrid inlets provided significant levels of suppression at both design and off-design throat Mach numbers with good aerodynamic performance. A comparison of inlet noise at quasi-static and forward-speed conditions in the wind tunnel showed a reduction in the fan tones, demonstrating the flight cleanup effect. High angles of attack produced slight increases in fan noise at the high acoustic directivity angles.**

## Nomenclature

| | |
|---|---|
| $D$ | = fan diameter, m (in.) |
| $f$ | = fan blade passage frequency, Hz |
| $L$ | = acoustic treatment length or inlet length, m (in.) |
| $M_{TH}$ | = 2-D throat Mach number |
| $N_l$ | = fan speed, rpm |
| $P_{avg}$ | = fan face average pressure, psi |
| $P_{max}$ | = fan face maximum pressure, psi |
| $P_{min}$ | = fan face minimum pressure, psi |
| PNL | = perceived noise level, PNdB |
| $P_\infty$ | = freestream pressure, psi |
| SPL | = sound pressure level, dB $20 \times 10^{-6}$ N/m$^2$ |
| $V_T$ | = fan tip speed, m/s (ft/s) |
| $V_\infty$ | = freestream velocity, knot |
| $\alpha$ | = angle of attack in reference to nacelle centerline, deg |
| $\theta$ | = directivity angle in reference to nacelle centerline at fan face, deg |
| $\dot{\omega}$ | = engine mass flow, kg/s (lb/s) |

## Introduction

EXTENSIVE research—analytical and experimental—has been and is still being conducted in efforts to understand and suppress the noise emitted from turbofan engine inlets. Even though the noise generation phenomenon is not completely understood, fan and inlet designs have been developed that reduce the noise generated or prevent its emission from the inlet. Three principal types of suppression inlets have been developed: 1) acoustically treated inlets, 2) sonic inlets, and 3) hybrid inlets. The acoustically treated inlets have the inner wall and several concentric rings lined with sound absorption material. Although these have proved effective in suppressing noise, they have not been accepted by the airlines because of added weight, loss of inlet pressure recovery, and the potential hazard of placing hardware in front of the fan. The sonic inlet employs very near sonic flow over a range of operating conditions. Variable geometry inlets are required which means additional weight and complexity. Wind tunnel tests of the sonic inlet have shown losses in total pressure recovery and increases in fan face pressure distortion which would adversely affect the propulsion system performance.

The hybrid inlet was developed to achieve the suppression effectiveness of both the treated and sonic inlets with substantially less weight and complexity, and fewer aerodynamic penalties. To achieve this goal, the hybrid inlet combines inner-wall acoustic treatment with moderate throat Mach number ($0.6 \leq M_{TH} \leq 0.8$), using fixed geometry hardware that has a small throat area and higher diffuser wall angles than conventional inlets. Several studies of small models[1-4] have shown that this combination of wall treatment and moderate throat Mach number enables the hybrid inlets to suppress the inlet noise effectively over the range of engine conditions from approach to takeoff power and to do so with good aerodynamic performance characteristics. This paper presents the results of a wind tunnel investigation of the acoustic and aerodynamic characteristics of hybrid inlets in an actual turbofan engine installation and the effect of flight conditions on these characteristics. Two hybrid inlets were tested in the Ames 40- by 80-Foot Wind Tunnel on a modified JT15D-1 turbofan nacelle. Both aerodynamic and acoustic performance were measured over a range of freestream velocities, inflow angles, and throat Mach number.

## Model Description

Two hybrid inlets and a baseline inlet were designed and fabricated for a modified JT15D-1 turbofan engine. Sketches of the three inlets and the hybrid design criteria are presented in Fig. 1 and Table 1. The short-takeoff-and-landing (STOL) hybrid inlet was designed to meet the stringent noise requirements proposed for powered-lift STOL aircraft and the conventional-takeoff-and-landing (CTOL) inlet was designed around the conventional turbofan-powered commercial transport aircraft. Sections of the inner wall of both hybrid inlets were lined with two thicknesses of bulk sound absorption material covered with 28% porosity sheet. The treatment was tuned to provide suppression of broadband as well as blade-passing-frequency (BPF) noise. The inlets were designed to allow replacement of the treated sections with hardwall sections for determination of lining effectiveness. The cylindrical baseline inlet was designed as a standard reference for the unsuppressed fan noise.

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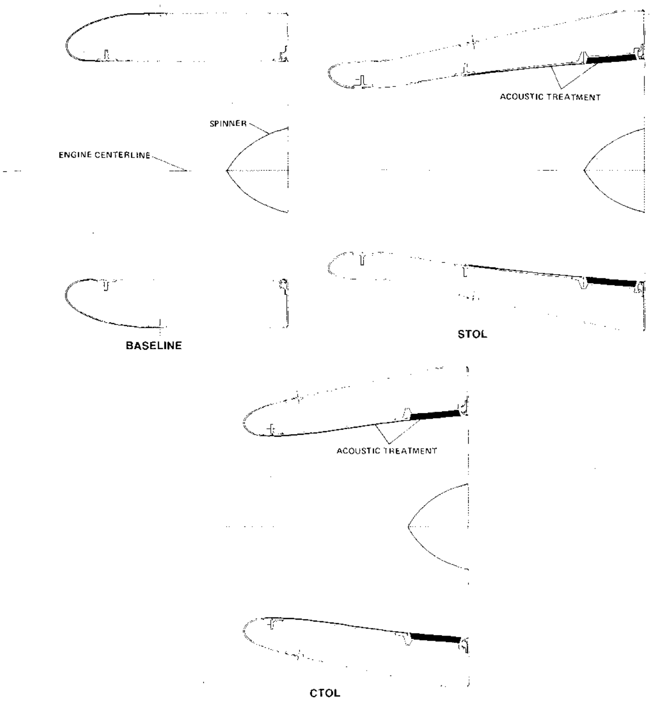


**Fig. 1 Inlet configuration sketches: a) baseline cylindrical inlet; b) CTOL hybrid inlet; c) STOL hybrid inlet.**

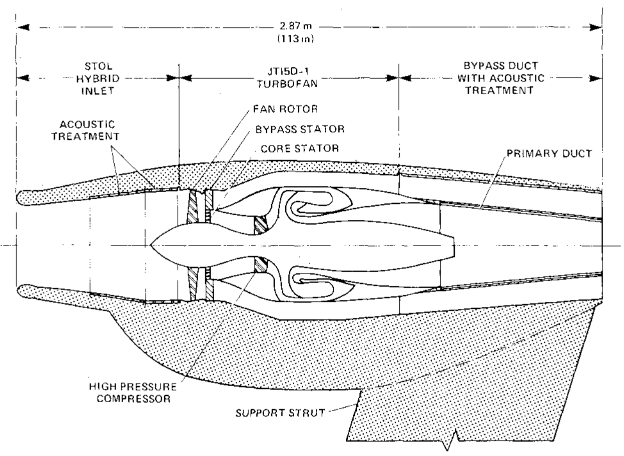


**Fig. 2 Hybrid inlet nacelle installation.**

A typical inlet installation on the turbofan nacelle is shown in Fig. 2. Several modifications were made to the original JT15D-1 to make it suitable for inlet testing. As a result of the work in Ref. 5, the inlet temperature probe was modified to make it flush with the inner wall, thus removing it as a possible fan noise source. The core stator assembly was modified to produce cutoff of the fan/stator interaction noise. The bypass duct was treated with bulk acoustic absorption material to suppress any fan noise normally emitted from the exhaust. The fan bypass duct exit area was increased to match mass flow, fan pressure ratio, and fan tip speed to the inlet requirements. The standard and modified JT15D-1 specifications are presented in Table 2.

## Test Description and Instrumentation

The inlet was installed on a single strut, 4.57 m (15 ft) above the floor of the wind tunnel test section, as shown in Fig. 3. The test section floor was lined with a 7.62-cm (3-in.) thick layer of acoustic foam. An acoustic calibration prior to the inlet test showed that the lining provided an essentially free-field acoustic environment in the frequency range of interest at the measurement distances used for the inlet model.

**Table 1 Hybrid inlet design parameters**

| Parameter | CTOL | STOL |
|---|---|---|
| $V_\infty$, knots | 160 | 80 |
| $\alpha$, deg | 20 | 20 |
| $\dot{\omega}$, kg/s (lb/s) | 33.9(74.75) | 28.8(63.50) |
| $M_{TH}$ | 0.72 | 0.77 |
| $V_T$, m/s (ft/s) | 427(1400) | 351(1150) |
| $N_l$, rpm | 15280 | 12550 |
| $f$, Hz | 7131 | 5857 |
| $L/D_{\text{inlet}}$ | 1.01 | 1.44 |
| $L/D$ treatment | 0.85 | 0.77 |

**Table 2 JT15D1 design features**

| | Standard | Modified |
|---|---|---|
| Fan pressure ratio | 1.5 | NA |
| Bypass ratio | 3.3 | NA |
| Hub/tip ratio | 0.405 | 0.405 |
| Rotor diameter, m(in.) | 0.533(21) | 0.533(21) |
| Maximum fan rpm | 16,100 | 16,000 |
| Rotor blades | 28 | 28 |
| Bypass stator vanes | 66 | 66 |
| Core stator vanes | 33 | 71 |
| Bypass vane/blade ratio | 2.36 | 2.36 |
| Core vane/blade ratio | 1.18 | 2.54 |
| Bypass rotor-stator spacing | 1.65 | 1.65 |
| Core rotor-stator spacing | 0.42 | 0.85 |
| Primary area, $m^2 (in.^2)$ | 0.051(79) | 0.051(79) |
| Bypass area, $m^2 (in.^2)$ | 0.0919(142.5) | 0.122(190) |

The noise measurements were made with four 0.635-cm (0.25-in.) microphones equipped with nose cones. One microphone was mounted on a weather vaning stand attached to a 3.66-m (12-ft) radius traversing rail. The microphone was mounted at the height of the model centerline and the rail was centered on the front of the fan. Another microphone was mounted on a straight traversing rail 2.74 m (9 ft) below and 1.22 m (4 ft) to the left of the model. Two microphones were mounted on a stationary stand near the inlet. The data from these microphones were used to discriminate the direct signal from the background noise at the condition where the latter is dominant. Only data from the circular-traverse microphone are presented in this paper. The remaining data will be published at a later date in a NASA technical publication.

The inlet aerodynamic performance was measured with a series of six fan face total pressure rakes which measured both steady-state and dynamic pressure. The pressure recovery, distortion, and separation boundaries were determined for both hybrid inlets from these rake data. The rakes were removed to make acoustic measurements. There were also surface static pressures, both steady-state and dynamic, at various azimuthal stations in the inlet. The static pressures near the throat were used with two-dimensional flow analysis of the inlets to compute the two-dimensional throat Mach number.

## Results and Discussion

### Aerodynamic Characteristics

The suppression capability of an inlet is irrelevant if the inlet does not have acceptable aerodynamic performance. The aerodynamic performance, in terms of pressure recovery and distortion, of the hybrid inlets tested is shown in Fig. 4 as a function of throat Mach number ($M_{TH}$) and angle of attack. Data from conventional inlets are plotted in Fig. 4 for comparison. The hybrid inlets have performance charac-

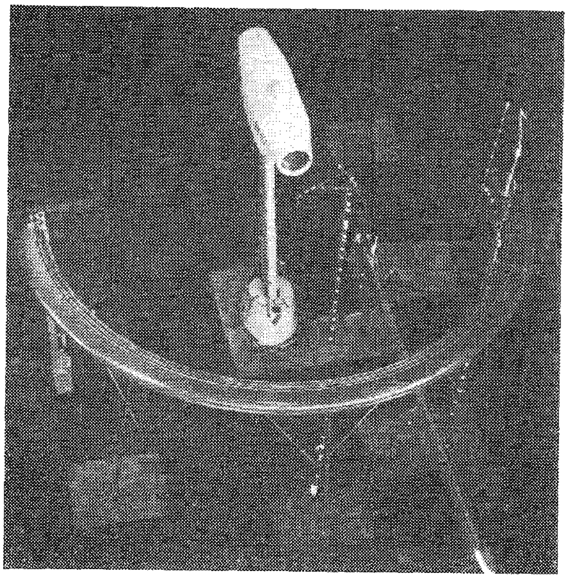

Fig. 3 Installation of hybrid inlet model in wind tunnel.

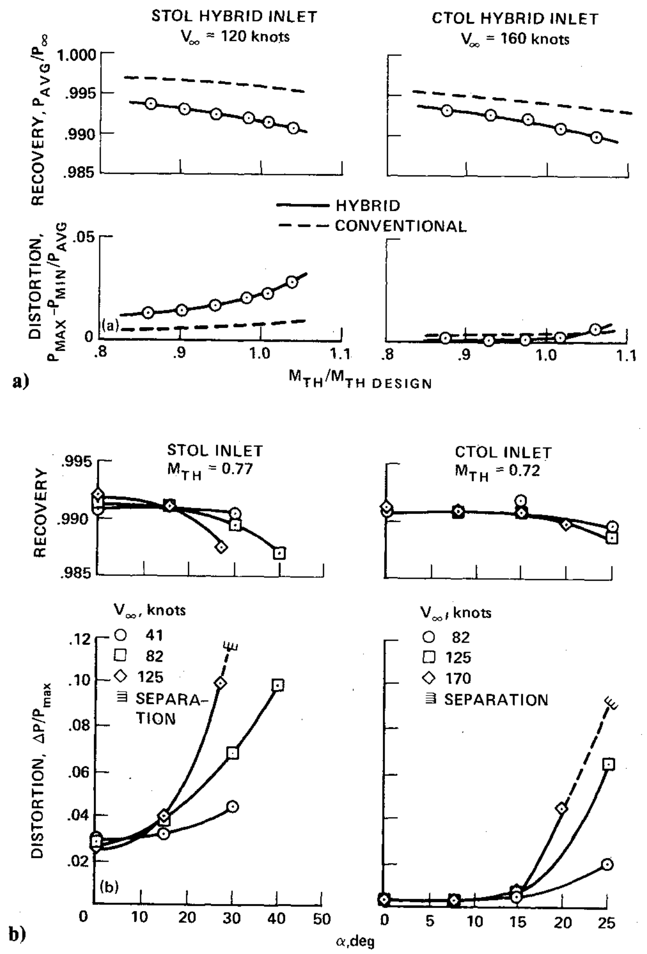


Fig. 4 Hybrid inlet aerodynamic performance: a) zero angle of attack; b) design throat Mach number.

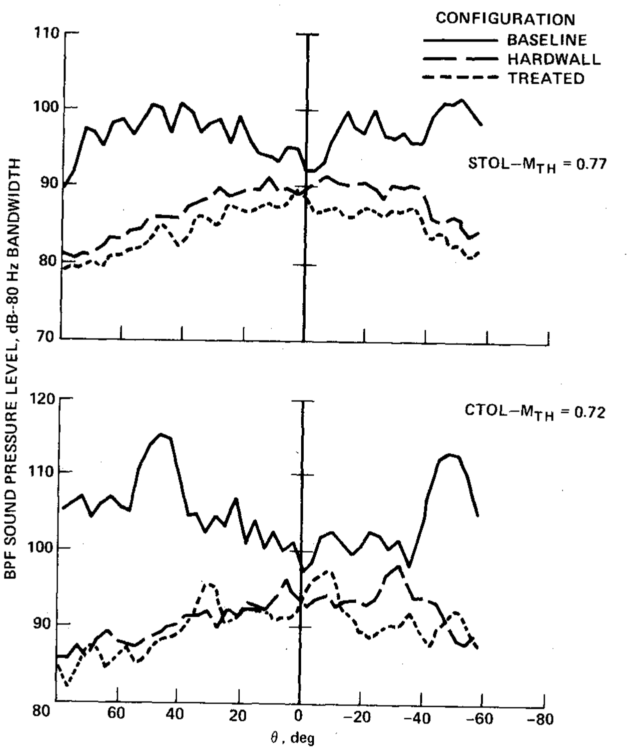


Fig. 5 Hybrid inlet blade-passage-frequency directivity at design $M_{TH}$, $V_\infty = 80$ knots, $\alpha = 0$ deg.

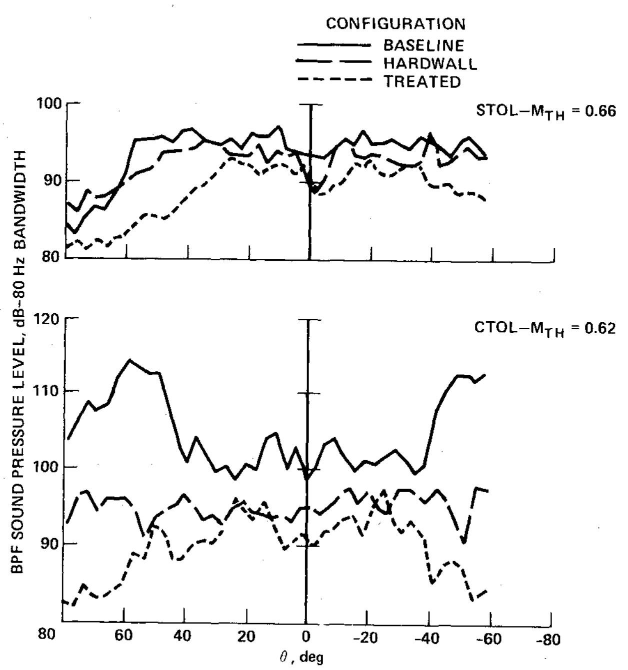


Fig. 6 Hybrid inlet blade-passage-frequency directivity at low $M_{TH}$, $V_\infty = 80$ knots, $\alpha = 0$ deg.

teristics that are comparable to conventional inlets with pressure recovery slightly less due to the smaller throat area relative to the fan face area and to the greater diffuser wall angle. The inflow distortion increase with angle of attack at each forward velocity was within acceptable limits and well below the maximum for the JT15D-1 fan. The STOL inlet, which had the higher distortion, was more sensitive to the severity of flight conditions, due both to the longer diffuser length and the higher design throat Mach number. The inlet distortion is essentially zero at $\alpha \leq 15$ deg at the design $M_{TH}$. Noise testing at higher angles of attack was restricted to ensure that internal separation was not affecting the results.

### Inlet Suppression Effectiveness

One of the primary objectives of this study was to determine the suppression effectiveness of hybrid inlets in a flight-type environment. These results are presented in Figs. 5-8. Because the noise emitted from a high-bypass-ratio turbofan inlet is dominated by the tone at the fan BPF, the acoustic

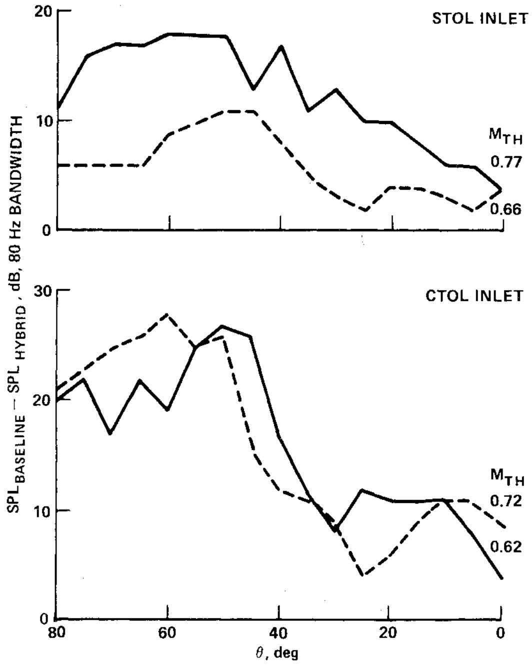


**Fig. 7 Hybrid inlet blade-passage frequency tone suppression; $V_\infty = 80$ knots, $\alpha = 0$ deg.**

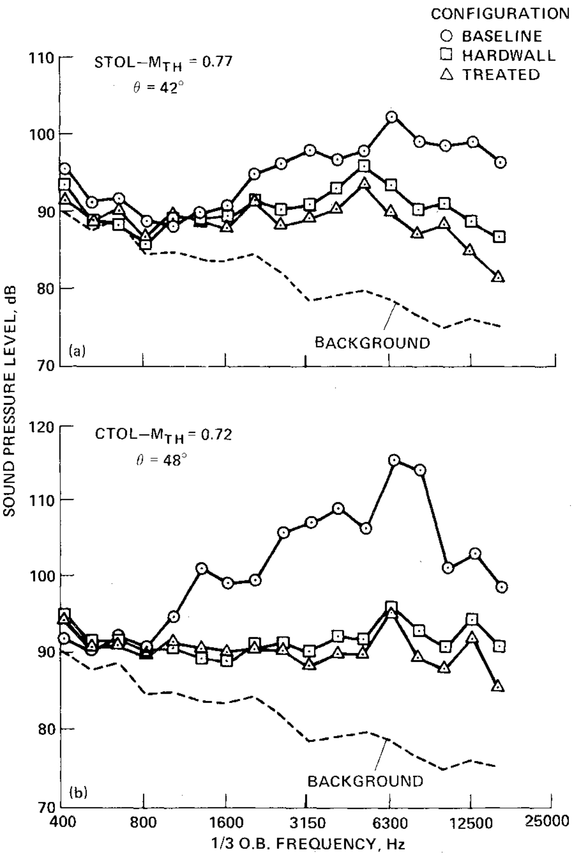


**Fig. 8 Hybrid inlet 1/3 octave band spectra, $V_\infty = 80$ knots, $\alpha = 0$ deg.**

results will be concentrated on the variation of this tone with forward acoustic angle $\theta$ measured from the nacelle centerline. To show the effects on broadband noise, spectral data at the directivity peak are also included. The BPF tone directivity at a forward speed of 80 knots for the baseline inlet and for each hybrid inlet at the design $M_{TH}$ are shown in Fig. 5; the same data for low $M_{TH}$ are shown in Fig. 6. At the

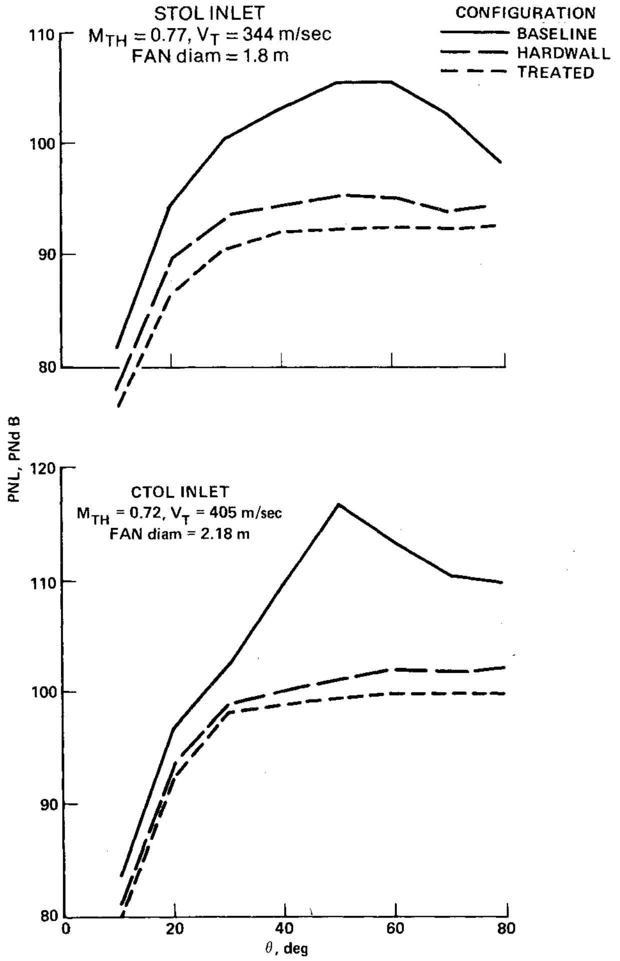


**Fig. 9 Full-scale sideline noise for hybrid inlets at design $M_{TH}$, $V_\infty = 80$ knots, 61 m (200 ft) sideline.**

design $M_{TH}$, the inlets were very effective in suppressing the BPF tone at $|\theta| \geq 30$ (suppression $\geq$ 10 dB) due primarily to the Mach number effect. At the low $M_{TH}$, the inlet treatment replaces most of the suppression lost due to lowering the $M_{TH}$. The total suppression of the BPF tone around the forward arc is shown in Fig. 7 for both hybrid inlets. The BPF tone suppression of as much as 27 dB by the CTOL inlet is essentially the same at both $M_{TH}$. However, the BPF tone suppression of the STOL inlet is lowered from 18 to 11 dB due to reducing the $M_{TH}$. The reason for this apparent anomaly is probably that the noise sources in the CTOL fan tip speed range are dominated by the rotor alone field, while in the STOL fan tip speed range this source is much lower. The rotor alone noise source is much easier to suppress with either treatment or with moderate $M_{TH}$ because of the intense concentration of noise from the blade tips propagating along the inlet wall. The peak angle spectral data in Fig. 8 show that the suppression at the design $M_{TH}$ is very broadband and confirms the presence of the rotor alone noise field in the CTOL fan tip speed range.

To determine the potential effect of the hybrid inlet suppression on propulsion system noise under flight conditions ($V_\infty$ = 80 knots), the model data were scaled to the size of typical commercial aircraft turbofan engines and then extrapolated to a 61-m (200-ft) sideline for which overall perceived noise levels (PNL) could be computed. The PNL directivities for both hybrid inlets are plotted in Fig. 9 for the design $M_{TH}$ and in Fig. 10 for the low $M_{TH}$. These results show that the PNL reduction for the CTOL inlet of 18 PNdB remains about the same for both $M_{TH}$, while the STOL inlet PNL reduction drops from 11 PNdB at design $M_{TH}$ to 7 PNdB at low $M_{TH}$.

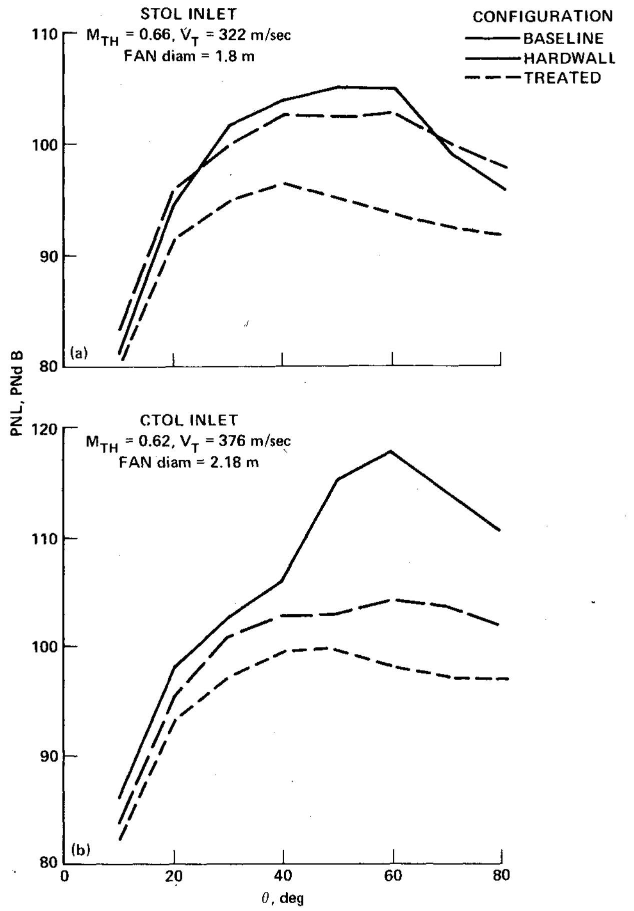


**Fig. 10 Full-scale sideline noise for hybrid inlets at low $M_{TH}$, $V_\infty$ = 80 knots, 61 m (200 ft) sideline.**

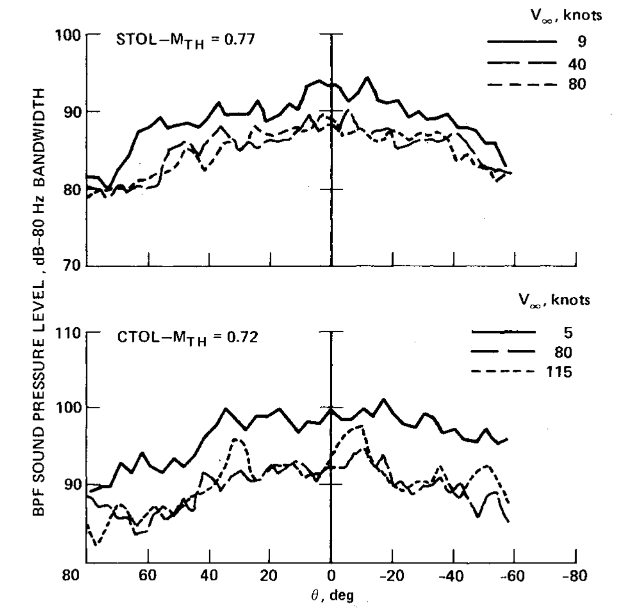


**Fig. 11 Effect of freestream velocity, blade-passage-frequency directivity, $\alpha$ = 0 deg.**

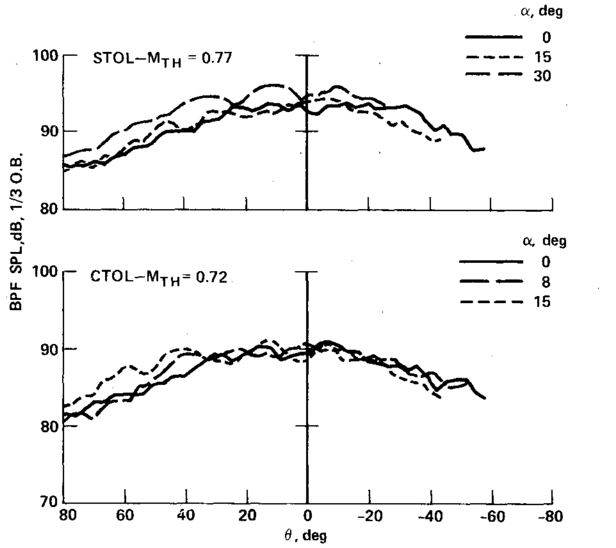


**Fig. 12 Effect of angle of attack on blade-passage-frequency directivity, $V_\infty$ = 80 knots.**

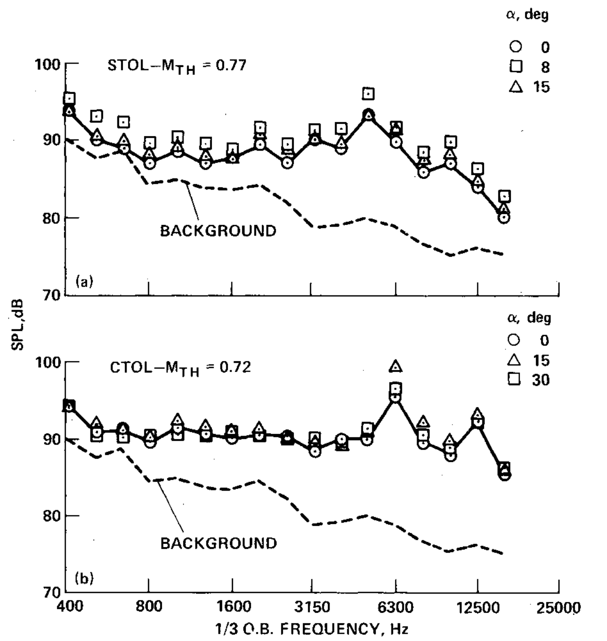


**Fig. 13 Effect of angle of attack on 1/3 octave band spectra, $V_\infty$ = 80 knots.**

### Forward Speed Effect

The suppression results presented thus far for the hybrid inlets are for a forward velocity of 80 knots and are consistent with the results from small-scale model studies.[4] However, the small-scale model data were obtained in a static environment and subsequent studies[5-8] have shown considerable reduction of fan noise between a static and flight environment. Even though a totally static environment could not be achieved in the Ames 40- by 80-Foot Wind Tunnel, the forward velocity was lowered enough (5-9 knots) to establish quasistatic conditions for investigation of forward velocity effects on the hybrid inlet noise. The effects of forward velocity on the BPF tone directivity for both hybrid inlets at their design $M_{TH}$ are shown in Fig. 11. The reduction in tone level is potentially greater if the true static conditions were taken as a baseline for the forward velocity comparison.

The fact that the reductions in BPF tone level occur over the entire directivity pattern and remain essentially constant at higher forward velocities aids in the understanding of the noise mechanism involved. The static-to-flight changes in fan noise are due to reduction of the noise caused by the interaction of the atmospheric turbulence with the rotor. This interaction tends to generate all mode orders which leads to a virtually flat directivity pattern. This noise source is usually lower than the rotor alone source at supersonic rotor tip speeds, which tends to be very peaked at $\theta$ = 50-60 deg. The hybrid inlet suppression easily reduces the rotor alone source since the noise is concentrated at the rotor tips and propagates along the inner wall. The rotor-turbulence interaction noise propagates over the entire duct and is, therefore, less affected by the wall treatment and moderate $M_{TH}$. Also, this source is reduced rapidly, with increasing forward velocity, to the point where other sources dominate. This explains why there is a marked forward velocity effect on the hybrid inlets, which occurs over the entire directivity pattern between the quasistatic and the first forward velocity tested, that does not change significantly as forward velocity is increased.

### Angle of Attack

Angle of attack $\alpha$ increases the boundary-layer thickness and flow distortion, both of which are possible sources of increased fan noise. Inlet separation, lip and diffuser, is also an obvious noise source. It is generally not considered because inlets are operated below the separated boundary and any extremes that are encountered are very transient. This being the case, angle-of-attack effects discussed herein are void of any separation effects. The angle-of-attack ranges for each of the inlets are representative of the limits the inlets would encounter in an aircraft installation. High angle of attack did increase the fan noise by 2 dB at high directivity angles for both inlets (see Fig. 12). The spectral data (Fig. 13) show that this effect influences the entire spectra of the STOL inlet, while in the CTOL inlet it is limited to the fan BPF and its harmonics. The exact source of this noise is not known. It does not seem to be related to the steady-state distortion, because the noise changes for the two inlets were equal, the distortion increase with the STOL inlet being almost 10 times that of the CTOL inlet. The relation of the effect and the dynamic distortion and the surface pressure fluctuations is being analyzed and will be presented in a separate paper.

## Conclusions

When tested in an actual turbofan installation in a simulated flight environment, the hybrid inlets provide significant levels of fan noise suppression, at both design and off-design throat Mach number conditions, with good aerodynamic performance. The suppression is over the entire frequency spectrum, thereby producing considerable perceived noise level reduction at the 61-m (200-ft) sideline when scaled to full-size turbofans. These types of inlets will provide sufficient fan noise suppression over a wide range of operating conditions without the use of variable geometry.

The hybrid inlet fan noise levels in the blade-passage-frequency range are lower at forward speed than at quasistatic conditions in the Ames 40- by 80-Foot Wind Tunnel. This demonstrates the flight cleanup on fan noise which is anticipated to be even greater if true static conditions typical of outdoor testing could have been achieved.

Slight increases in hybrid inlet fan noise levels occurred at angles of attack of 30 deg for the STOL inlet and 15 deg for the CTOL inlet. These increases occurred at high acoustic angles and did not appear to be related to fan face total pressure distortion levels.

## References

[1] Mathews, D.C. and Nazel, R.T., "Inlet Geometry and Axial Mach Number Effect on Fan Noise Propagation," AIAA Paper 73-1022, Oct. 15-17, 1973.

[2] Paul, D.L., "Quiet Clean Short-Haul Experimental Engine; Aerodynamic Characteristics of 30.5 cm Dia. Inlet," NASA CR 134,866, Aug. 1975.

[3] Jutres, R.R., "Single Stage, Low Noise Advanced Technology Fan; Vol. VI, Fan Acoustics," NASA CR 134,894, March 1976.

[4] Motsinger, R.E., "Analytical and Experimental Study of Acoustic Performance of Segmented Lines in a Compressor Inlet," NASA CR 2882, Sept. 1977.

[5] Hodder, B.K., "Further Studies of Static-to-Flight Effects on Fan Tone Noise Using Inlet Distortion Control for Source Identification," NASA TM X-73183, Dec. 1976.

[6] Cumpsty, N.A. and Lowrie, B.W., "The Cause of Tone Generation by Aero-Engine Fans at High Subsonic Tip Speeds and the Effect of Forward Speed," ASME Paper 73-WA/GT-4, Detroit, Mich., 1973.

[7] Roundhill, J.P. and Schaut, L.A., "Model and Full Scale Test Results Relating to Fan Noise In-Flight Effects," AIAA Paper 75-465, Hampton, Va., 1975.

[8] Fieler, C.E. and Merriman, J.E., "Effects of Forward Velocity and Acoustic Treatment on Inlet Fan Noise," AIAA Paper 74-946, Los Angeles, Calif., 1974.