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Forward Flight Effects on Fan Noise from Supersonic 2-D Inlets

L. Venkatakrishnan*
National Aerospace Laboratories, Bangalore 500 017, India
and
A. Krothapalli†
Florida State University, Tallahassee, Florida 32310

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I. Introduction

THE success of high-speed civil transport aircraft depends on the minimization of its environmental impact. Foremost among these is the aircraft community noise due to takeoff and landing. In addition to jet noise, forward-propagated engine fan noise is a significant component of the overall noise. The noise radiation directivity pattern is influenced by the design of the inlet. This is especially true for supersonic inlets where features such as translating centerbody, support struts, and auxiliary doors are contributing factors.

Previous studies on supersonic inlets under static conditions by Bangert et al. [1] and by Trefny and Wasserbauer [2] at low-speed forward flight have shown that the forward-propagated fan noise forms a significant portion of the takeoff and landing noise. Woodward et al. [3] acoustically tested a supersonic P-type inlet in simulated low-speed flight at up to Mach 0.2 and concluded that the auxiliary doors significantly increased the fundamental tone of the fan noise. Nuckolls and Ng [4] developed a modified door geometry, which helped to reduce the circumferential distortion of the flowfield near the fan face, which was tested by Detweiler et al. [5], at simulated takeoff conditions, without the effect of forward flight.

The purpose of the present investigation is to determine the flight effects on the fan noise, from a 2-D supersonic inlet coupled to a turbofan engine simulator. The testing was accomplished for a simulated low-speed flight up to Mach 0.2 in the Fluid Mechanics Research Laboratory (FMRL) anechoic wind tunnel and statically (zero freestream velocity) in the FMRL anechoic chamber. Acoustic results are presented using a far-field microphone traversing in an arc. For comparison, data from a conventional flight contoured inlet (CTOL) under similar conditions are also presented.

II. Experimental Arrangement

A model turbofan engine simulator was used in conjunction with the supersonic inlet to provide a characteristic engine noise signal. The turbofan engine simulator is a 10.4 cm diam Tech Development Model 460 and is similar to that used in the investigation by Detweiler et al. [5] at Virginia Polytechnic Institute (VPI). The model simulates a JT9D turbofan engine. A single stage turbine, run by compressed air at 300 psig that can run at a maximum design speed of 80,000 rpm, powers the fan. The simulator incorporates 18 fan blades and 26 stator vanes. The Reynolds number based on fan diameter and tip speed is 1.7×10^6. Nuckolls and Ng [4] and Miller and Ng [6] have shown that despite the difference in Reynolds number, the small scale inlet used here is similar to a full scale inlet tested by Woodward et al. [3] insofar as acoustic trends and inlet noise mechanisms are concerned.

The test inlet used here is a 1:6 scale 2-D bifurcated inlet developed by Boeing, hereafter referred to as the Boeing inlet. Flat plate inlet guide vanes (IGV) are used for uniform fan inlet flow. For comparison with earlier studies, measurements were carried out on a CTOL inlet obtained from VPI without IGVs in the same setup at FMRL.

The data were acquired at fan speeds of 50,000 and 70,000 rpm corresponding to about 60% (60PNC-percent corrected design speed) and 88% (88 PNC) of the design speed, respectively. The 50,000 rpm was to simulate the aircraft at landing approach and the 70,000 rpm for the takeoff conditions. The corresponding blade tip speeds were 265 and 382 m/s (subsonic and supersonic), respectively.

It is important to achieve the proper blade loading for comparison of noise spectra. The required fan stagnation pressure ratio is 1.38 at 70,000 rpm. For this the exit area of the fan had to be reduced to $0.00355\ m^2$ from $0.008\ m^2$. A choke plate at the exit achieved this effect.

The test section of the wind tunnel incorporates an anechoic chamber with dimensions of $2.15 \times 2.7 \times 2.15$ m. The simulator was hung from the ceiling 1.5 m above the ground, to avoid exciting a ground vortex in the inlet flowfield. The acoustic measurements for the noise spectra in the far field were taken at 10 locations (from 20 to 110 deg, angles measured from inlet axis) along a circular arc of radius 1.22 m. The measurements could not be taken from the inlet centerline due to the presence of the wind tunnel entry. The testing of the inlets in forward flight was carried out by running the tunnel at $M = 0.2$ to simulate takeoff and landing approach conditions.

The acoustic data presented have a resolution of 48.8 Hz. The overall sound pressure level (OASPL) was calculated by numerical integration of the spectra after the addition of the microphone correction and included the contribution of the combination tones and the jet noise. Combination tones or "buzz-saw" noise, which occur at supersonic fan tip speeds, generate an acoustic signature in the forward arc containing energy at harmonics of the engine shaft rotation frequency.

The spectra were integrated from 1000 Hz onward to filter out the contribution from the tunnel fan. The tunnel noise levels over the region of interest are about 30 dB lower and are hence acceptable. The data from the forward flight tests were corrected for the effect of wind velocity on the fixed microphone in the manner suggested by Krothapalli et al. [7].

III. Results and Discussion

The validation of the data acquired was carried out by running the simulator with the CTOL inlet obtained from the VPI inlet for the

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*Scientist Experimental Aerodynamics Division, Member AIAA.
†Don Fuqua Professor, Department of Mechanical Engineering, Fellow AIAA.

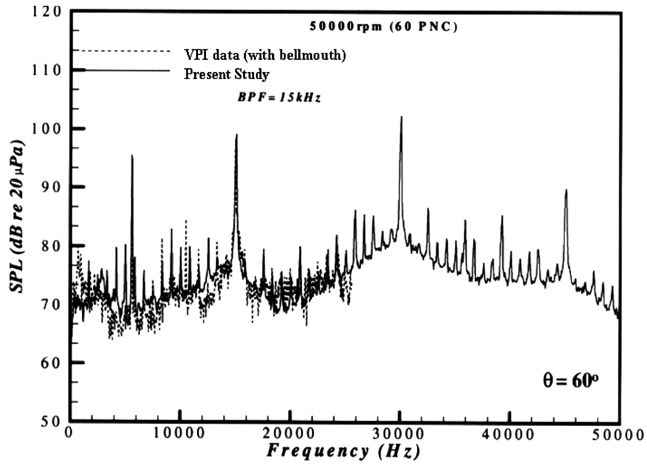

Fig. 1 Comparison of spectra at $\theta = 60°$ for the CTOL inlet against data from VPI at static conditions.

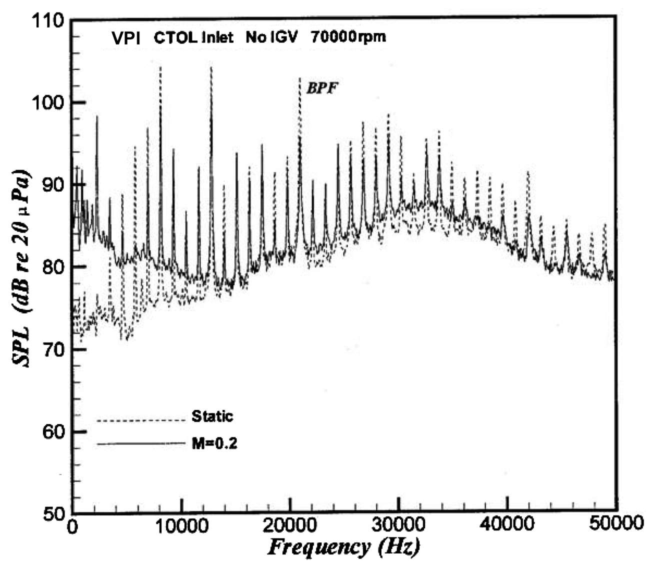

Fig. 2 Effect of forward flight on CTOL inlet at takeoff condition: typical spectrum at 60°.

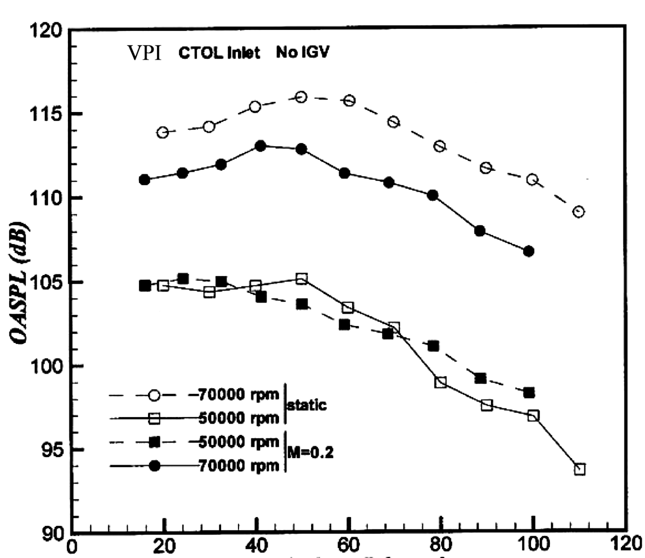

Fig. 3 Effect of forward flight on variation of OASPL for CTOL inlet.

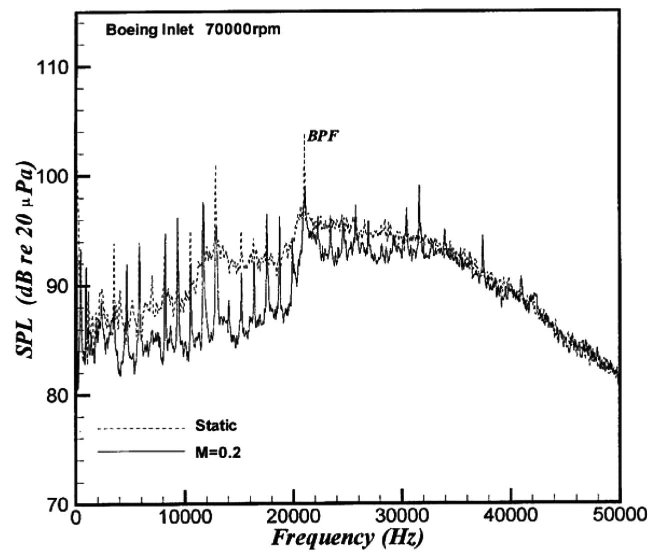

Fig. 4 Effect of forward flight on Boeing inlet at takeoff condition: typical spectrum at $\theta = 60°$.

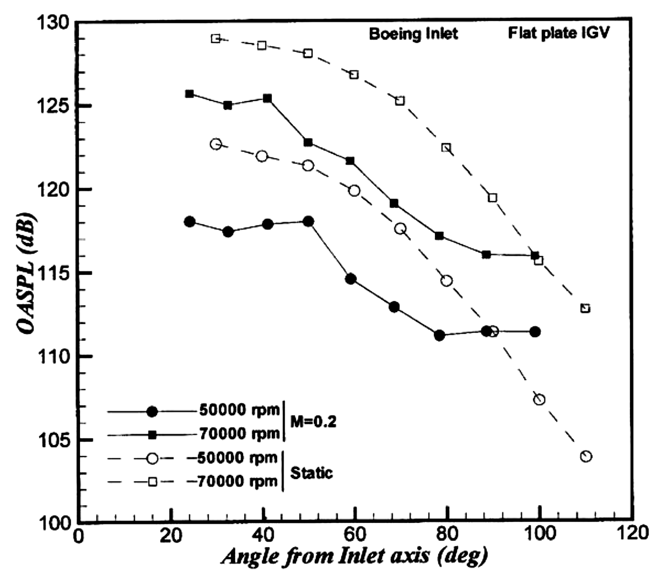

Fig. 5 Effect of forward flight on OASPL of Boeing inlet.

landing approach and takeoff conditions and comparing the results with the data from VPI. Figure 1 shows this comparison and the agreement is quite good considering that the two tests are carried out in different though very similar facilities. The VPI data extended to only 25 kHz for this case (see Venkatakrishnan et al. [8] for details).

Figure 2 shows a typical spectrum for the CTOL inlet (no IGVs) without and with forward flight for the takeoff condition case. The blade passage frequency (BPF) of 21 kHz corresponding to this condition is clearly seen in the figure. It is seen that the static case at takeoff condition has combination tones, owing to the supersonic tip speeds.

The effect on the OASPL is seen in Fig. 3 for both takeoff and landing cases. It is seen that the reduction with forward flight is much greater for the takeoff case than for the landing approach case. This is because the combination tones present in the takeoff case reduce due to the reduction in relative blade tip velocity with forward flight. This results in a lower OASPL. Further, for the landing approach condition case, an increase is observed in the aft region of the fan. This is due to the fact that though the exhaust was ducted out in both static and flight cases, the exit from the chamber to the tunnel was open in the forward flight case, which accounts for the increase in

OASPL beyond 90 deg for the landing approach condition case. This effect is not so prominent in the takeoff condition case due to the much higher SPL of the fan itself.

The 2-D bifurcated inlet was fitted to the engine with flat plate inlet guide vanes. These were required to straighten the flow. No auxiliary doors were provided in the test inlet. Hence all results are for flow through the inlet with closed auxiliary doors. For this case, data were taken only from 30 deg onward due to the much longer inlet and the size constraints of the anechoic chamber.

Figure 4 shows the typical frequency spectra at the takeoff condition, for the static and forward flight cases. The spectra show the expected peaks at 21 kHz. The combination tones are again seen in the figure due to the reasons explained earlier. The effect of forward flight is seen to be much greater here than for the CTOL inlet. There is seen about 3–4 dB reductions over the entire range. A similar trend is seen for the landing condition case (see Venkatakrishnan et al. [8] for details).

The angular variation of OASPL for both takeoff and landing conditions in the static and flight cases is shown in Fig. 5 showing reduction at all angular locations. Unlike in the CTOL inlet, here the reductions for both conditions seem to be comparable. Again the effect of the jet exhaust is seen in the aft region of measurement.

The effect of forward flight is to manifest larger reduction in OASPL of the Boeing inlet compared to the CTOL inlet. In addition to the possible reasons already detailed for the CTOL case, it is possible that the increase in the freestream Mach number helps to reduce the flow separation at the lip, which is present in the static conditions. While no aerodynamic measurements were carried out in this study, this was observed in earlier studies (Trefny and Wasserbauer [2], Detweiler et al. [5]) who showed that for a supersonic (P-type) inlet, lip flow separation persisted at all configurations of the auxiliary inlets under static conditions. Increasing the freestream Mach number to 0.2 (as in the present study), reduced lip flow separation for all configurations. This reduction took the form of reduced distortion and thus reduces noise radiated from the inlet.

IV. Conclusion

The objective of this study was to evaluate the acoustic performance of a 2-D bifurcated supersonic inlet under simulated takeoff and landing approach conditions of the fan in forward flight. Tests were also carried out on a CTOL inlet to provide a baseline reference. The data show that the effect of forward flight is to lower the OASPL over the entire region with the more pronounced effect on the BPF level for the takeoff case for both types of inlets. While the effect of reduction in OASPL with forward flight is well known, the reduction was seen to be greater for the supersonic inlet. It is suggested that the reasons for this greater reduction relate to the reduction in lip flow separation and consequentially higher circumferential flow distortion as found by earlier studies. However, detailed aerodynamic measurements have to be carried out to verify this supposition.

Acknowledgments

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