Forward Flight Effects on Externally Blown Flap Noise

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Abstract

ONE promising concept for powered-lift short takeoff and landing (STOL) aircraft is the externally blown flap (EBF), with conventional turbofan engines exhausting either above or below the wing. Several methods exist for predicting EBF noise at zero flight speed. However, takeoff and approach flight speeds of EBF aircraft will be roughly ¼ the exhaust velocity. It is likely that such flight speeds would alter the exhaust jet flow properties and therefore the noise radiation. Measured noise beneath EBF models in external flows has been found to decrease at some but not all frequencies. These reductions generally are least at frequencies that dominate full-scale annoyance-weighted noise levels. If the effects of forward flight on EBF noise mechanisms were understood, it might be possible to choose configurations having less noise annoyance at takeoff and approach.

Contents

Results of Model Test Program

Simple small under-the-wing (UTW) and upper-surface-blowing (USB) models with 5-cm nozzle diameter were tested[1] in an acoustic wind tunnel. Measured maximum turbulence levels in the exhaust jet near the flap surfaces were found to decay nearly linearly with the ratio of simulated flight velocity V_0 to exhaust velocity V_J. These data nearly matched the corresponding results for an isolated exhaust jet at the same axial location.[2] It is convenient to regard EBF noise as a sum of surface-radiated noise and direct-radiated quadrupole noise from the deflected exhaust jet.[3] Surface-radiated noise, proportional to turbulence level squared, would be expected to vary as $20 \log(1-V_0/V_J)$. Typical takeoff and approach flight Mach numbers are small enough so that convective amplification effects on amplitude and spectrum can be neglected, although the Doppler effect on frequency measured during an aircraft flyover should be included.

For measurements directly beneath a UTW, the low- and moderate-frequency parts of the spectra (Strouhal numbers up to 0.5) tend to be dominated by surface-radiated noise. Increased tunnel airspeed caused decreased noise amplitude in this frequency region and decreased overall sound pressure level (OASPL). These measured decreases were predicted by the foregoing expression. The high-frequency quadrupole noise did not vary consistently with V_0 at constant V_J. If such noise depends on relative velocity between the exhaust jet and the flaps that deflect it, no variation would be expected.

Spectrum amplitudes measured directly beneath a USB were found to decrease by about $40 \log(1-V_0/V_J)$ at Strouhal numbers less than 0.2, with little or no change at Strouhal numbers greater than 0.5. Frequency at peak amplitude was increased as V_0 increased. These spectra, measured in simulated forward flight, could be obtained from the zero tunnel speed data by use of an empirical adjustment. Amplitudes were decreased by the analytically expected increment $20 \log(1-V_0/V_J)$, and frequencies were multiplied by $(1+V_0/V_J)$. That is, forward speed caused the expected decrease of amplitude, accompanied by an unexpected increase of frequency for USB spectra. Noise directivity for both configurations, measured between 60- and 120-deg angles in the flyover plane, was unaffected by forward flight

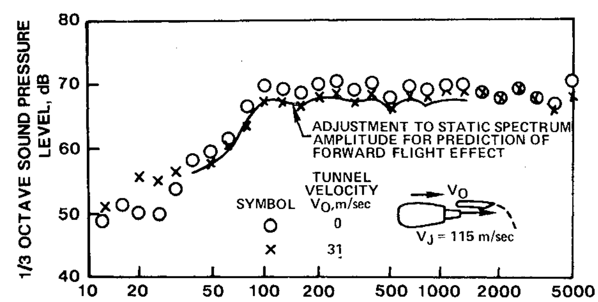

Fig. 1 Measured and predicted forward flight effects on NASA UTW noise spectrum.

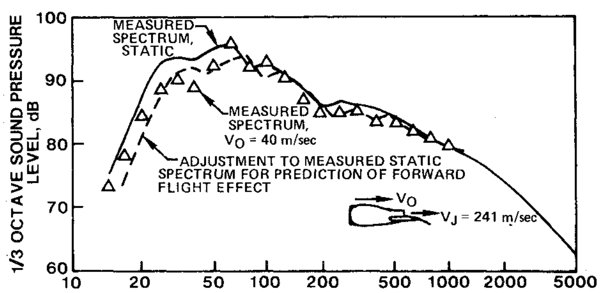

Fig. 2 Measured and predicted forward flight effects on NASA USB noise spectrum.

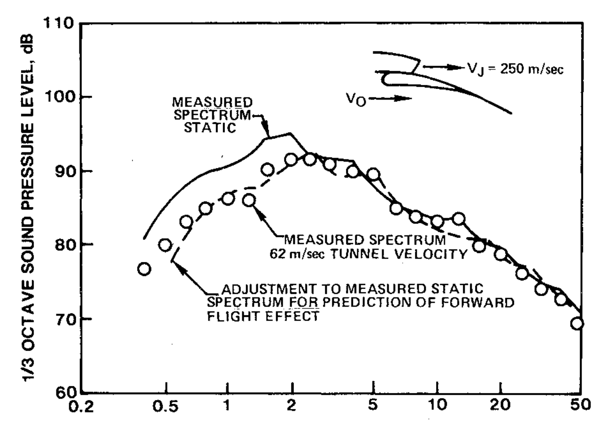

Fig. 3 Measured and predicted forward flight effects on Lockheed USB noise spectrum.

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except for conditions at which the external flow blew the exhaust jet away from the flap surface.

Comparisons with Other Data

Under the Wing

Forward flight effects on noise from several types of STOL configurations have been measured in the NASA Ames Research Center 40×80 wind tunnel. Models included a large UTW in the landing configuration.[4] This model had four JT15D engines with 0.64-m fan duct exit diameter. Measured maximum dynamic pressure in the jet exhaust upstream of the flap increased about 7% when forward speed was increased from zero to a typical approach speed. The resulting increase in local exhaust velocity at the flaps was expected[4] to cause less than 1 dB increase of noise. Measured ⅓ octave spectra for these forward speeds of 0 and 31 m/s at 115-m/s jet exhaust velocity are reproduced in Fig. 1. Although this exhaust velocity is lower than would normally be used in EBF approach flight, the velocity ratio is realistic. Noise reduction caused by decreased turbulence intensity at this velocity ratio of 0.27 would be 20 log $(1-V_0/V_J)$, or about 2.7 dB. Combining this with the effect of increased local velocity on surface-radiated noise causes a 2-dB predicted noise reduction. Applying this reduction at constant frequency closely matches the measured forward flight spectrum between 50 and 1000 Hz frequency. Between 1600 and 4000 Hz, there was no measured effect of forward speed on SPL. At higher frequencies, the measured spectra were dominated by tones from the turbofan engines that powered the model. The observed 2-dB decrease of flap impingement noise cited in that paper therefore was predicted as a combination of the effects of decreased turbulence level and increased local mean velocity. Measured spectrum shape in forward flight was predicted by correcting the amplitude but not changing the frequency.

Upper-Surface Blowing

The effect of forward speed was reported[5] for a large USB model tested in this wind tunnel at simulated takeoff conditions. This model had two JT15D engines with aspect ratio 5 nozzle exit ducts. Spectra for velocity ratios of 0 and 0.165 are reproduced in Fig. 2. Applying the calculated decrease of amplitude and increase of frequency to the measured static-velocity spectrum (solid curve) yields the predicted spectrum in forward flight (dash curve). This prediction matched the data within ±2 dB except at frequency bands containing engine tones. The predicted 1.6-dB reduction of OASPL agreed with the measured 2-dB decrease.

Forward flight effects on noise of an USB model were reported[6] by Lockheed-Georgia Company. This small model had an aspect ratio 2 nozzle exit duct, with the exhaust area of a 3.6-cm-diameter circle. Data were given for velocity ratios of 0 and 0.25. These data are shown in Fig. 3. The dash curve represents the measured static spectrum (solid curve) adjusted in both amplitude and frequency for prediction of the spectrum in forward flight. Agreement between this prediction and the measured spectrum was within 1 dB for most of the frequency bands.

Conclusion

Spectra measured beneath EBF models at zero flight speed can be readily adjusted to yield good predictions of spectra at typical takeoff and approach speeds. For USB, this requires adjustments to both amplitude and frequency.

References

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[6] Gibson, J.S. and Searle, N., "Characteristics of USB Noise," Paper 15, *Powered-Lift Aerodynamics and Acoustics,* NASA SP-406, May 1976, pp. 227-239.