Approximate Prediction of Airframe Noise

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Theme

AIRFRAME noise from aerodynamically clean airframes is assumed to be trailing-edge noise caused by convection of the wing turbulent boundary layer past the wing trailing edge. Resulting maximum flyover noise is predicted from an existing solution for trailing-edge noise plus estimates of turbulent boundary-layer integral scale length and turbulence intensity. Typical airplanes with retracted or well-faired landing gear but with wing-mounted engine nacelles and extensive trailing-edge flap-track shields generate about 8 dB more than this minimum trailing-edge noise. Resulting predicted acoustic intensity varies with airspeed to the fifth power, in agreement with a linear regression analysis of flight data.[1] Trailing-edge noise has been previously inferred[2] to be the mechanism for airframe noise because of the observed fifth-power velocity dependence. In contrast, other analyses[3,4] have assumed a lift dipole directivity associated with fluctuating-drag noise mechanisms and have predicted a sixth-power velocity dependence.

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This analysis starts with the solution derived by Ffowcs-Williams and Hall[5] for noise caused by one turbulent eddy convected past a sharp trailing edge. Such noise must be multiplied by the number of eddies along a wing of span b. With Λ taken as the transverse integral scale length of turbulence having intensity α normal to the surface, this number of eddies was empirically found[6] to be $b/8\Lambda$. Then the mean square acoustic pressure radiated in the flyover plane by an airplane in level flight at velocity U and altitude h is

$$\overline{p^2} = (4/9)(\rho^2/a)U^5\alpha^2(\Lambda b/h^2)\sin^2\theta\cos^2(\theta/2) \quad (1)$$

Maximum intensity that would reach a stationary observer is radiated when the angle θ is about 71° above the approach horizontal direction. Depending on flight Mach number, the aircraft could be ahead or behind the overhead position when maximum noise reaches the observer. This predicted retarded-time angle for maximum noise agrees with data.[7]

For this direction angle, sea-level standard air density, and speed of sound, 1% turbulence level normal to the surface, and velocities normalized relative to 100 m/sec, Eq. (1) becomes

$$\text{OASPL} = 50\log(U/100\,\text{m/sec}) + 10\log(\Lambda b/h^2) + 122\,\text{dB} \quad (2)$$

Transverse integral scale length is of the order of 1/3 the boundary-layer thickness. At the trailing edge

$$\Lambda = \delta/3 = 0.13\,cR_c^{-0.2} = 0.13(S/b)R_c^{-0.2} \quad (3)$$

where S is the wing area. Reynolds numbers R_c of interest range from about 1×10^6 to 40×10^6. The factor $R_c^{-0.2}$ then varies from 0.063 to 0.030, causing only a 3 dB spread in calculated noise. Taking an arbitrary constant Reynolds number of 2.6×10^6 for sailplanes,

$$\text{OASPL} = 50\log(U/100\,\text{m/sec}) + 10\log(S/h^2) + 100.3\,\text{dB} \quad (4)$$

Flyover noise calculated from Eq. (4) is compared in Fig. 1 with data[3,7,8] for aerodynamically clean airframes. The solid symbols are test points for which the spectra had a large spike

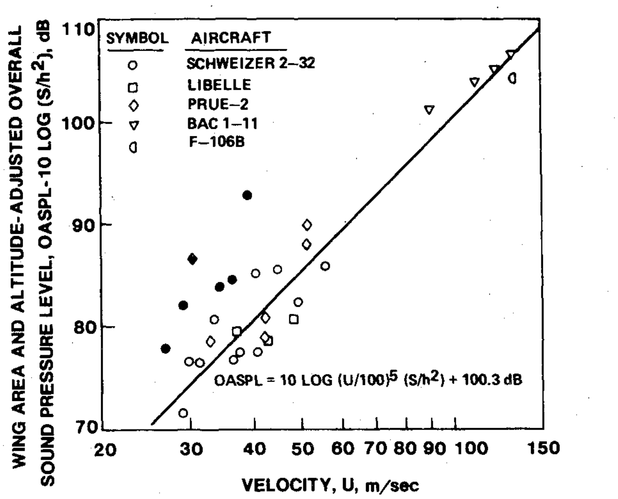

Fig. 1 Measured and calculated maximum OASPL for aerodynamically clean airframes.

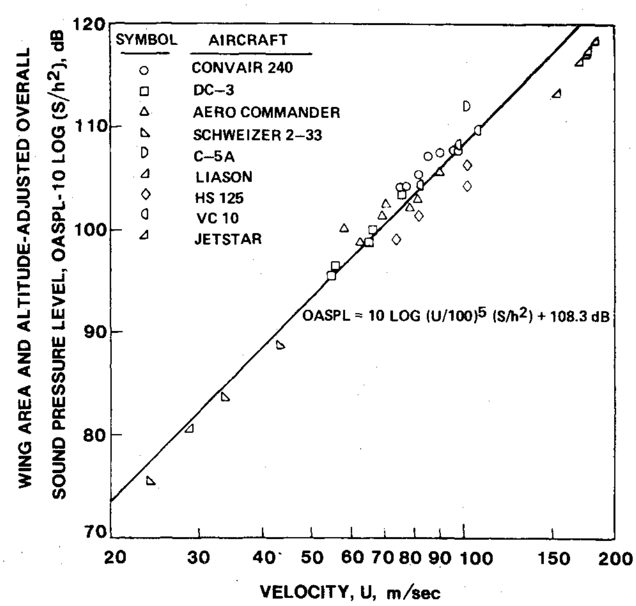

Fig. 2 Measured and calculated maximum OASPL for conventional airframes with retracted gear and flaps.

Presented as Paper 76-526 at the 3rd AIAA Aero-Acoustics Conference, Palo Alto, Calif., July 20-23, 1976; synoptic received July 19, 1976. Full paper available from AIAA Library, 750 Third Avenue, New York, N.Y. 10017. Price: Microfiche, \$2.00; hard copy, \$5.00. **Order must be accompanied by remittance.**

Index category: Aircraft Noise, Aerodynamics (including Sonic Boom).

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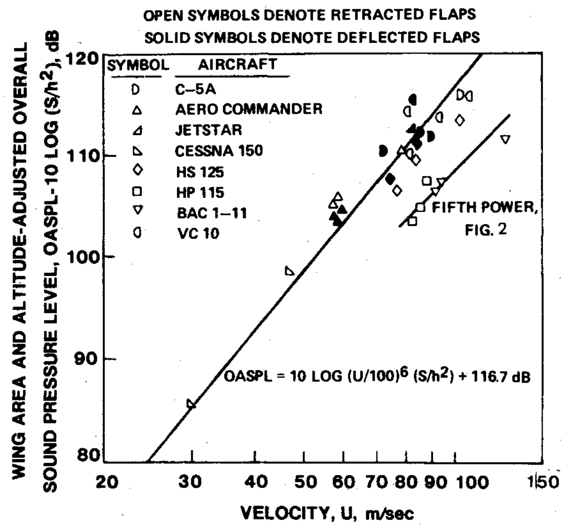

Fig. 3 Measured and calculated maximum OASPL for airframes with extended landing gear.

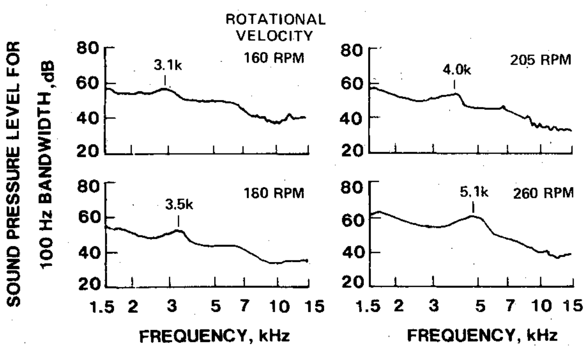

Fig. 4 Broadband noise spectra of two-blade S-55 helicopter rotor; measurement direction 75° below rotor disc; 3050 lb thrust. Lines denote calculated peak frequencies for blade airframe noise.

in one 1/3-octave band. Excluding those laminar-instability tone points, the data are predicted by Eq. (4) within 2.5 dB standard deviation. Aspect ratio does not enter into the prediction, and aspect ratio for these airframes varies by a factor of ten. In contrast, most empirical equations for airframe noise[1,3,4] contain aspect ratio raised to a large negative exponent.

Airframe noise data for other aircraft with retracted landing gear[2,3,8] are plotted in Fig. 2. The solid line is 8 dB above what was calculated by Eq. (4). It matches the data within 1.8 dB standard deviation except for data from the Jetstar and HS 125. Those two business jets are only about 4 dB louder than was predicted by Eq. (4) for aerodynamically clean wings.

Bluff-body noise from extended landing gear should vary with velocity to the sixth power and the ratio of landing-gear frontal area to altitude squared. To a crude approximation, landing-gear frontal area is proportional to wing area. Flyover noise data for eight airframes with fixed or extended landing gear are plotted in Fig. 3. Two aircraft, the HP 115 and BAC 1-11, had smaller noise levels which were predicted by the fifth-power velocity equation of Fig. 2. Flyover noise data for the other six aircraft are given within 2.3 dB standard deviation by

$$\mathrm{OASPL} = 60\log(U/100\ \mathrm{m/sec}) + 10\log(S/h^2) + 116.7\mathrm{dB} \quad (5)$$

Effects of flap deflection (solid or open symbols) on OASPL were unimportant for airframes with extended landing gear.

If trailing-edge noise occurs for fixed-wing aircraft, it should also occur in the spectra of helicopter rotors. This noise should be largest, and tone noise smallest, near the rotational axis. Spectra in this direction are dominated by lift-fluctuation noise caused by ingestion of atmospheric turbulence. Narrowband spectra for a direction 75° below the rotor disc of a full-scale hovering rotor[9] are shown in Fig. 4 for four rotational speeds. A high-frequency peak, generally called high-frequency excess noise, protruded above the lift-fluctuation noise. Peak frequency for airframe noise is given[1,4] by 1.3 times airspeed, divided by wing thickness. Taking the characteristic airspeed for a helicopter as 85% of the tip speed gives the calculated frequencies shown by vertical lines in Fig. 4. This prediction matches the observed high-frequency peaks. Thus the same noise mechanism that dominates the spectra for airframe noise also occurs in spectra of helicopter rotor-blade noise.

References

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