Aerodynamic Noise of High Speed Ground Vehicles

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Aerodynamic Self-Noise Due to Fluid/Surface Interaction

Consider a single class of interactions:

- Turbulent boundary layer flows
    - Direct radiation
    - Interaction with discontinuity (trailing edge)
- Generated sound equivalent to a distribution of acoustic dipole sources

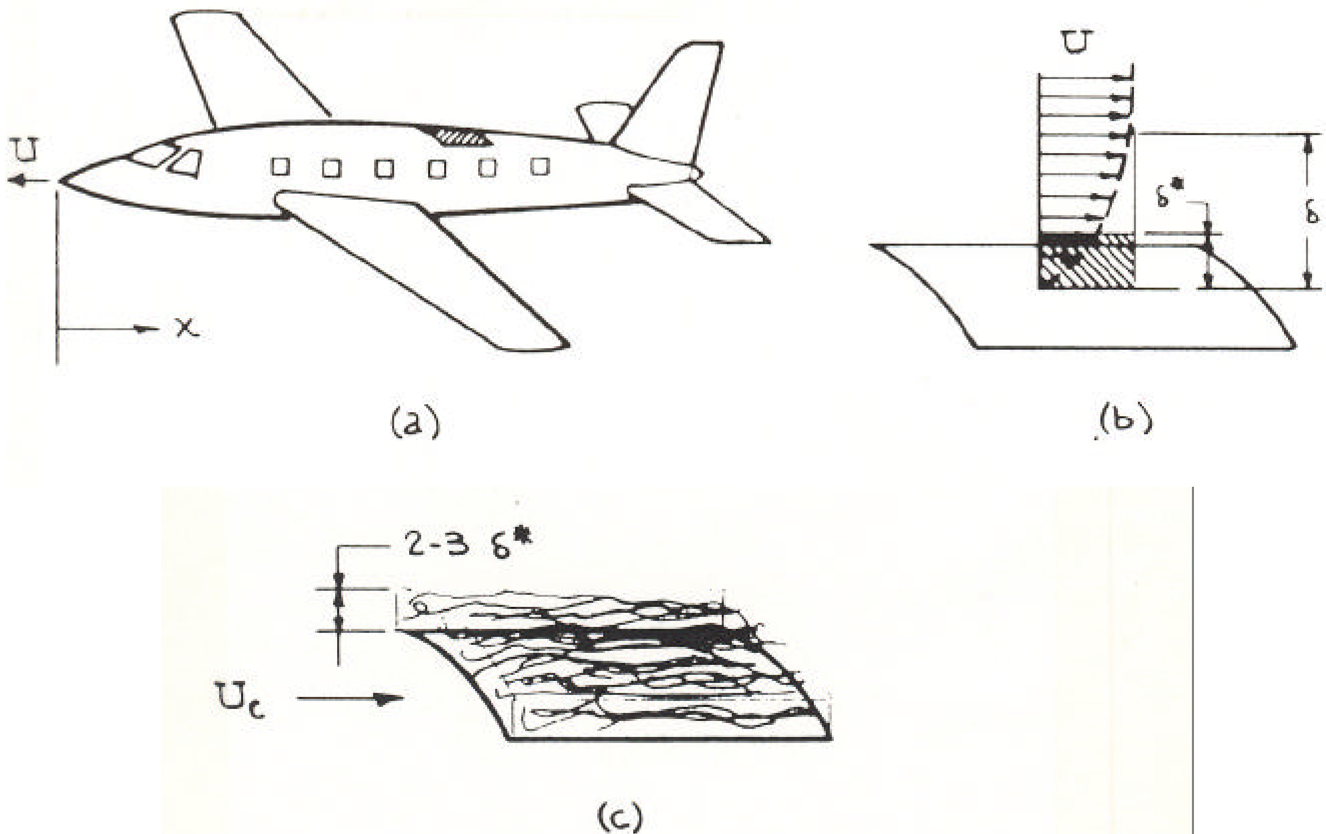


Fig. 10.1. Turbulent boundary layer on aircraft fuselage.

FROM: LYON, TRANSPORTATION NOISE GROZIER 1973.

ACOUSTIC DIPOLE SOURCE (wall pressure)

$$p = \frac{\rho c k^2 \, |\vec{D}| \cos\theta}{4\pi r}$$

where, $k = \omega / c$ (wave number) and $|\vec{D}|$ (magnitude of dipole moment)

Assuming dipole oriented normal to surface:

$$|\vec{D}| = (1 / k\rho c) \; p_W \, A_c$$

a function of wall pressure and surface area, therefore:

$$p = (k A_c / 4\pi r) \; p_W$$

Turbulent boundary layer wall pressure measurements

- Schroder / Lotch:

$$p^2_W(f) = 3.16 \times 10^{-5} \quad \rho^2 \delta^* U^3 \; [\, 1 + (\pi S)^2 \,]^{-(3/2)}$$

where Strouhal number $S = f\delta^*/U$ and δ^* = B. L. displacement thickness

Integrated over all frequency:

$$p^2_W(f) = 3.16 \times 10^{-5} \quad \rho^2 \delta^* U^3 \; [\, U/\pi\, \delta^* \,]$$

- Wilmarth:

$$p_W = 0.006\, q$$

where $q = (½)\rho U^2$, free stream dynamic pressure

- Hardin

(1/3) $OBSPL$ $(Re: 20\mu Pa)$ $= 38 + (A\, \rho^2 U^8 / c^2)$

where A = surface area, level constant in all bands

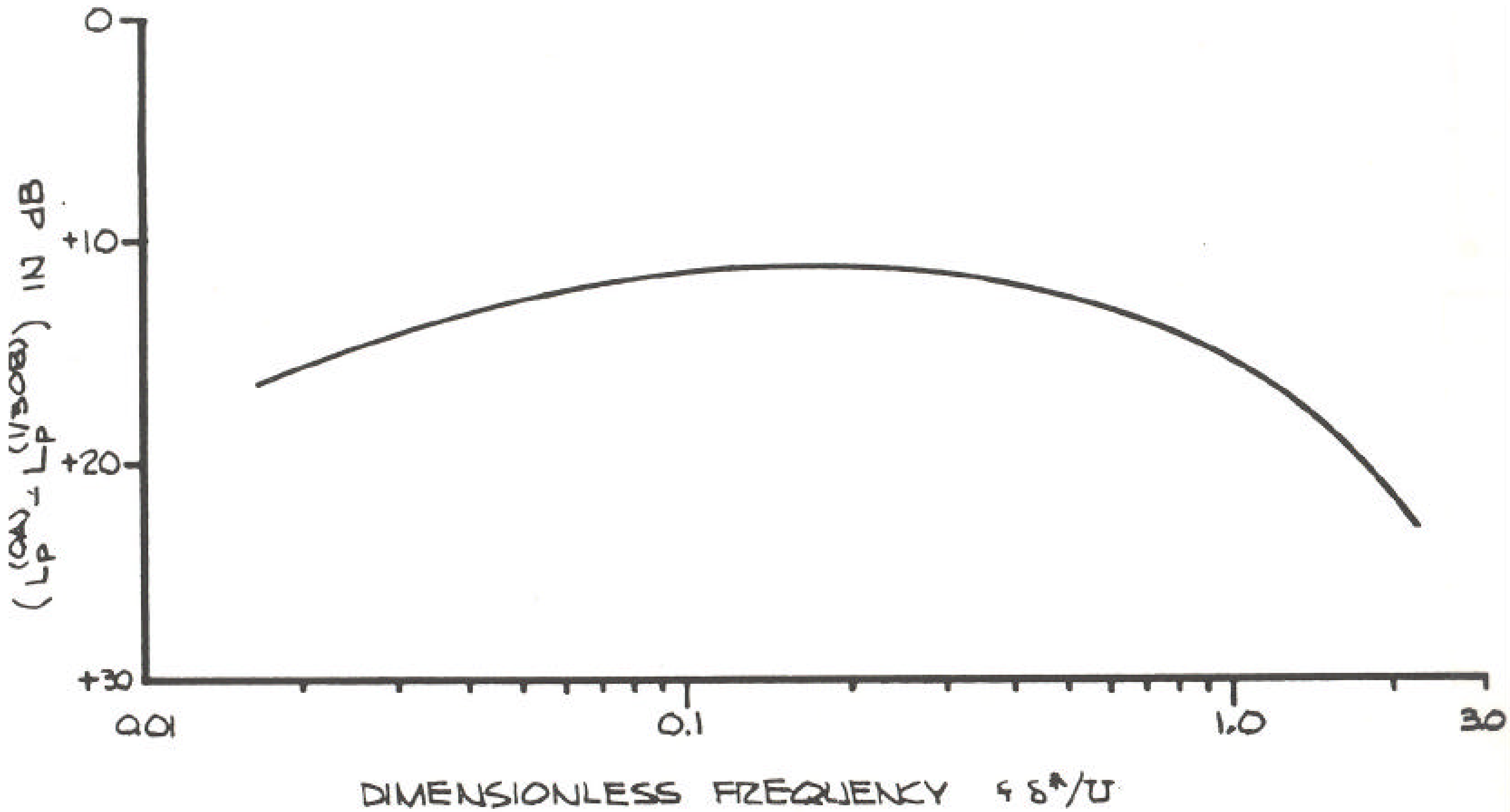


Fig. 10.2. Nondimensional third octave band spectrum of boundary layer and pressure fluctuations (Ref. 2).

FROM: LYON, TRANSPORTATION NOISE, GROZIER, 1973.

Trailing Edge Noise

- Hayden:

$$PWL\left[Re: 10^{-12}\ watts\right] = -25 = 10\log\left[\delta W U^{6}\right]$$

where δ is B.L. thickness, W is length of wetted edge

Broadband spectrum peaks at $0.16 = (f\,\delta/U)$

Power in watts $\Pi = 10^{**}\left[\ (PWL\ /\ 10) - 12\ \right]$

Far Field intensity of dipole

$$I_r = (\ 3\ /\ 4\pi r^2)\ \ \Pi = \cos^2\theta$$

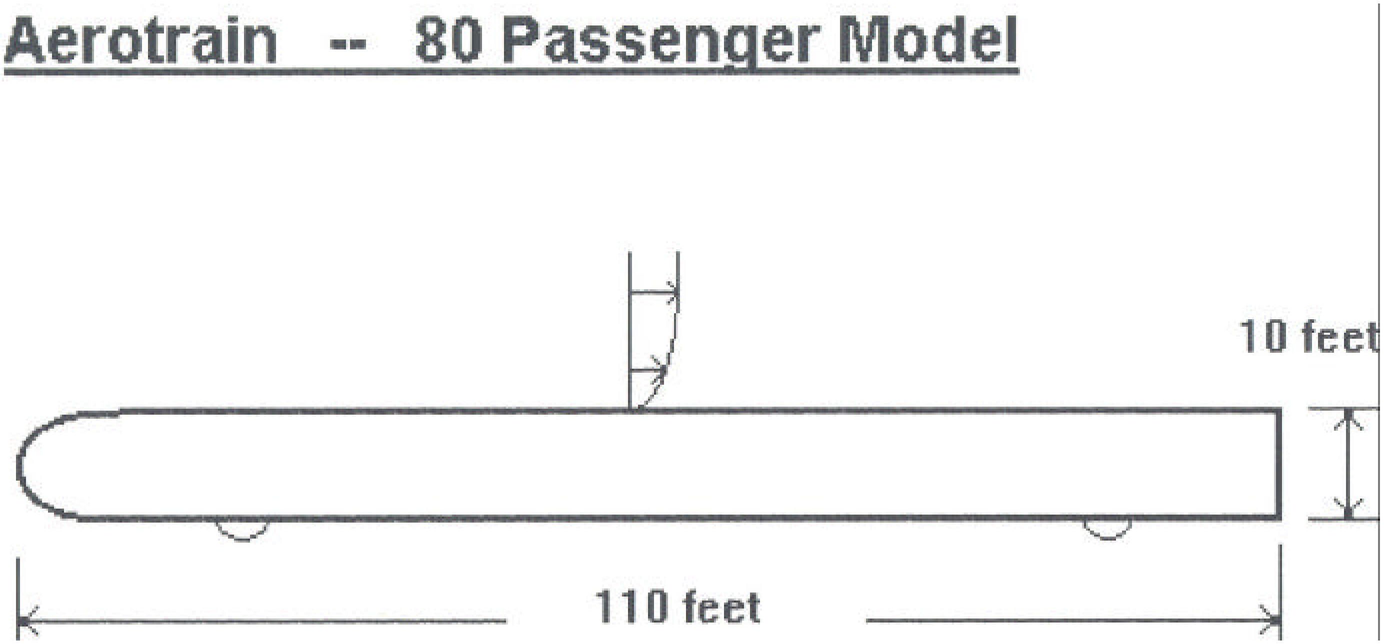
High Speed Train Model

- Noise calculated for 80 passenger Aerotrain

- Vehicle speeds of 150 to 300 MPH

- Listener sideline distance of 50 feet

Aerotrain -- 80 Passenger Model



Boundary layer thickness

- For 150 MPH:

Reynold's number 50 feet from nose = 6.9×10^7

at trailing edge Re = 1.5×10^8

- For 300 MPH: Re (50 feet) = 1.4×10^8

Re (T.E.) = 3.0×10^8

Turbulent boundary layer thickness using the Karman- Schoenherr skin friction method:

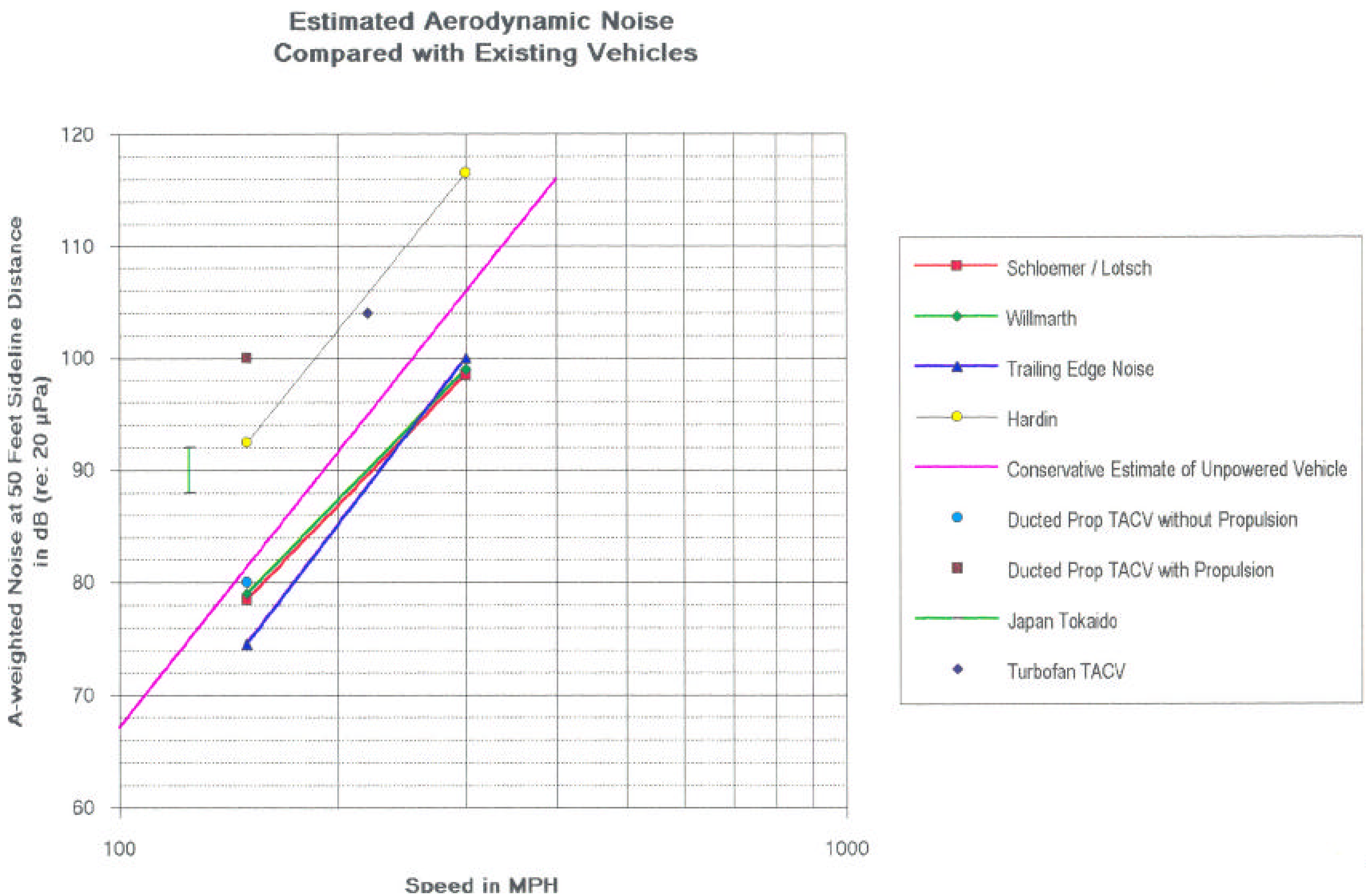
150 MPH: d (50 ft) = 0.67 feet and d (T.E.) = 1.31 feet

300 MPH: d (50 ft) = 0.61 feet and d (T.E.) = 1.20 feet

boundary layer displacement thickness $d^* \sim d / 8$

- For this analysis, assume $d^* = 0.1$ ft
- Turbulence correlation area determines dipole strength

$A_c = 2\,[U/\omega]^2$ *and* $N = A / A_c$



Estimated Aerodynamic Noise
Compared with Existing Vehicles
A-weighted Noise at 50 Feet Sideline Distance
in dB (re: 20 μPa)
120
110
100
90
80
70
60
100
1000
Speed in MPH
Schloemer / Lotsch
Willmarth
Trailing Edge Noise
Hardin
Conservative Estimate of Unpowered Vehicle
Ducted Prop TACV without Propulsion
Ducted Prop TACV with Propulsion
Japan Tokaido
Turbofan TACV

Conclusions

- Boundary layer noise and trailing edge noise calculated for a high speed train by several methods.
- B.L. noise - 78 to 93 dB(A) at 150 MPH
  - 98 to 116 dB(A) at 300 MPH
- T.E. noise - 75 dB(A) at 150 MPH
  - 100 dB(A) at 300 MPH
- Calculated noise levels match available test data.
- Total aerodynamic noise A – weighted levels of at least 80 dB(A) at 150 MPH and 102 dB(A) at 300 MPH present a significant noise floor for high speed ground transportation, regardless of propulsion method.