Aerodynamic Noise of High Speed Ground Vehicles

Bennett M. Brooks, P.E.

Brooks Acoustics Corporation

27 Hartford Turnpike

Vernon, CT 06066

Presented at the Acoustical Society of America 125th Meeting

Ottawa, Canada – 18 May 1993

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

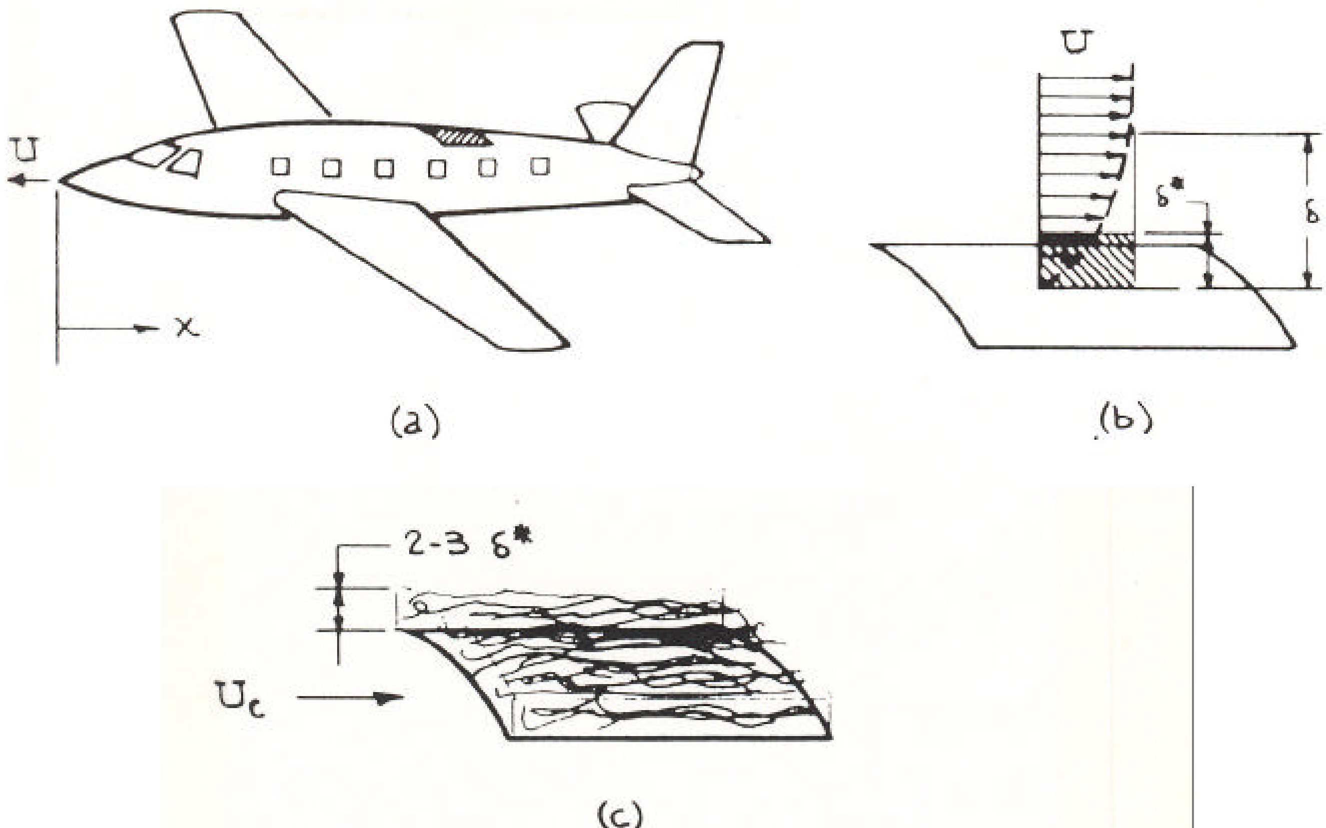


Fig. 10.1. Turbulent boundary layer on aircraft fuselage.

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

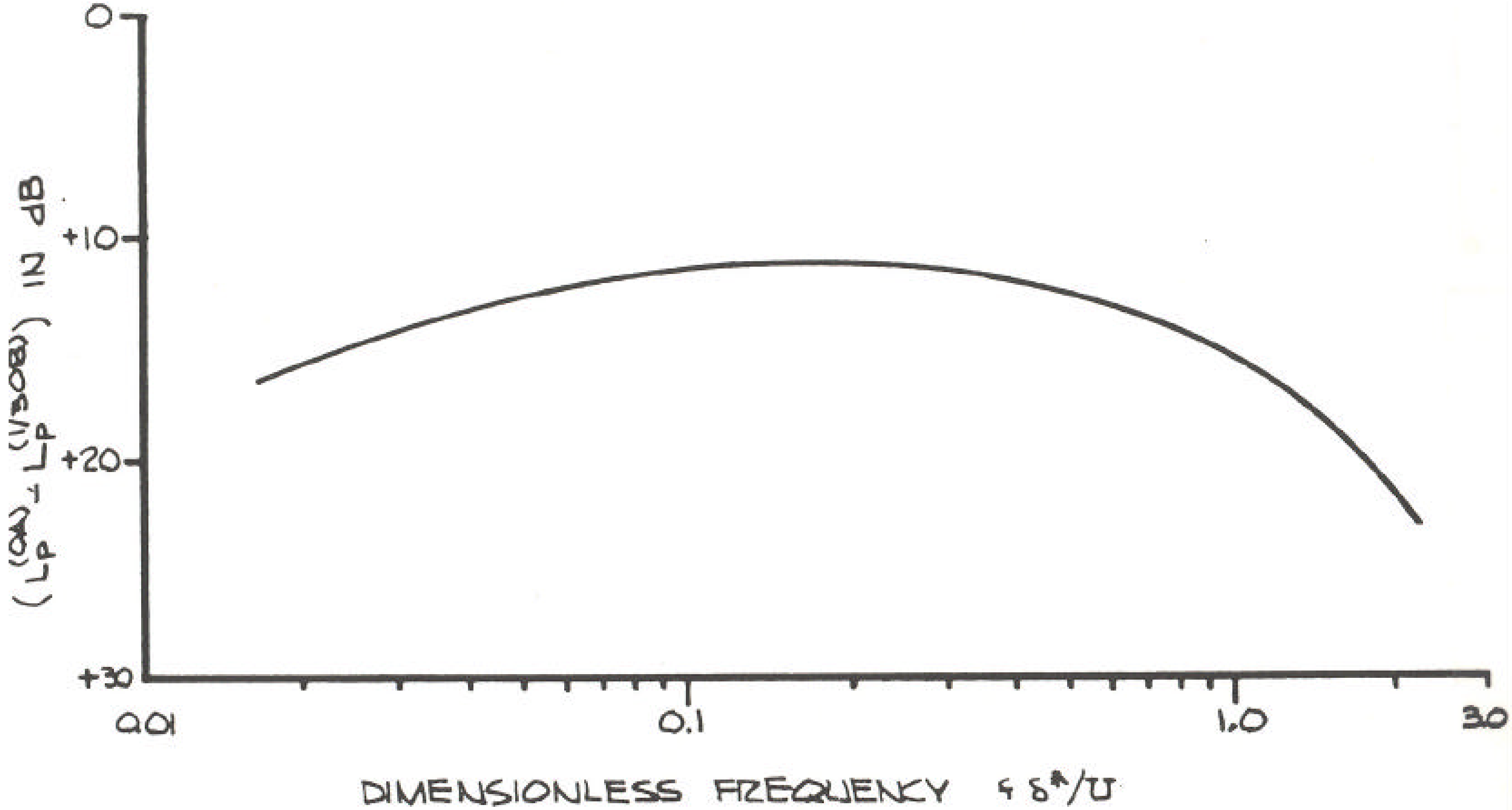


Fig. 10.2. Nondimensional third octave band spectrum of boundary layer and pressure fluctuations (Ref. 2).

FROM: LYON, TRANSPORTATION NOISE, GROZIER, 1973.

Trailing Edge Noise

- Hayden:

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

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

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

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

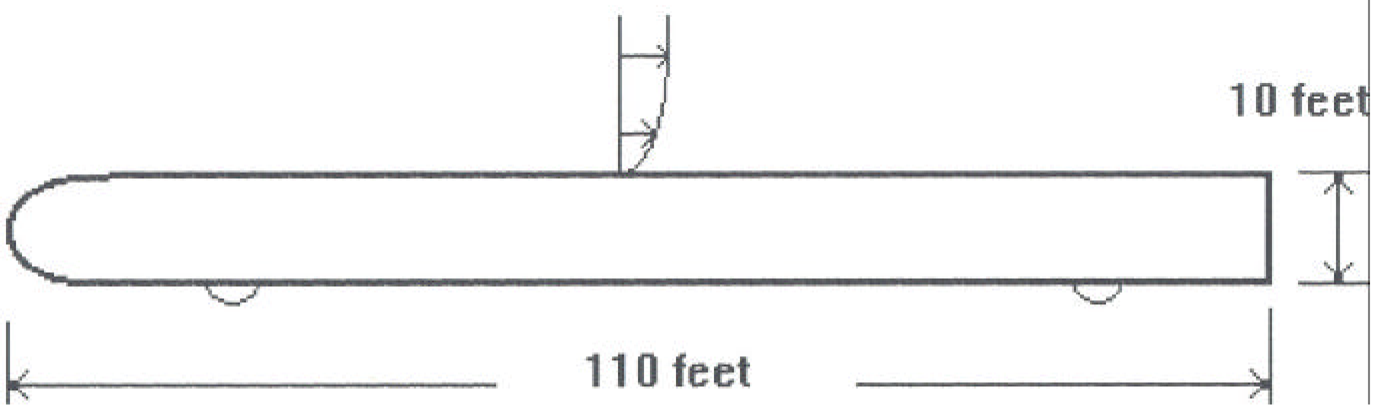
Far Field intensity of dipole

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

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:

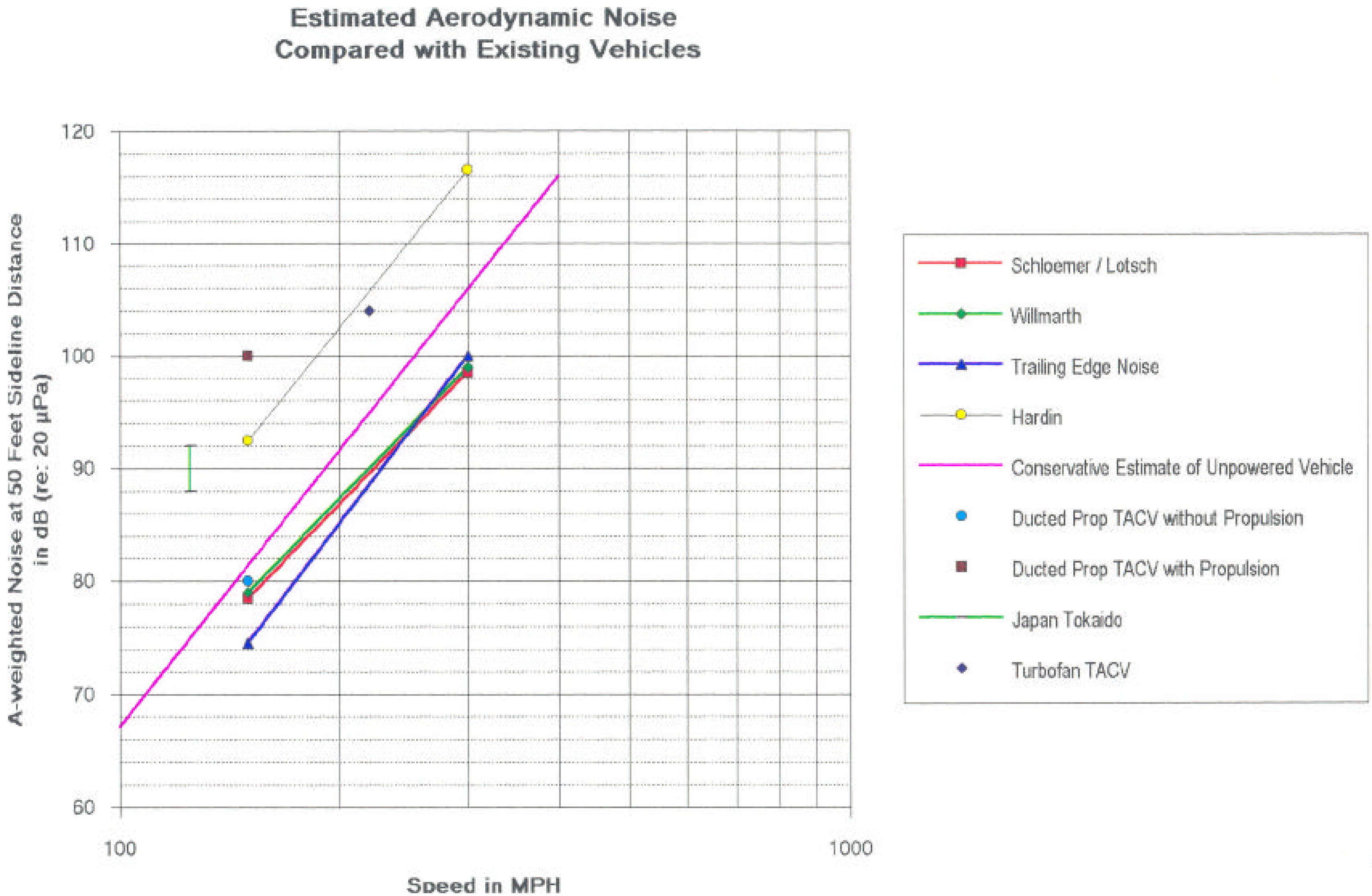
150 MPH: d (50 ft) = 0.67 feet and d (T.E.) = 1.31 feet

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

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


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.