Nonlinear distortion. A sound wave produces an expansion and a compression of the air in which it is traveling. We find from Eq. (2.6) that the relation between the pressure and the volume of a small "box" of the air at 20°C through which a sound wave is passing is

$$P = \frac{0.726}{V^{1.4}} \tag{9.84}$$

where

V is specific volume of air in $\mathrm{m}^3/\mathrm{kg} = 1/\rho_0$
P is absolute pressure in bars, where 1 bar $= 10^5$ Pa

This equation is plotted as curve AB in Fig. 9.12

Assuming that the displacement of the diaphragm of the drive unit is sinusoidal, it acts to change the volume of air near it sinusoidally. For large changes in volume, the pressure built up in the throat of the horn is no longer sinusoidal, as can be seen from Fig. 9.12. The pressure wave so generated travels away from the throat toward the mouth.

If the horn were simply a long cylindrical pipe, the distortion would increase the farther the wave progressed according to the formula (air assumed) [14,15]

$$\frac{p_2}{p_1} = \frac{\gamma + 1}{2\sqrt{2}\gamma} k \frac{p_1}{P_0} x = 1.21 k \frac{p_1}{P_0} x \tag{9.85}$$

where

p_1 is rms sound pressure of the fundamental frequency in Pa.
p_2 is rms sound pressure of the second harmonic in Pa.
P_0 is atmospheric pressure in Pa.
$k = \omega/c = 2\pi/\lambda$ is wave number in m^{-1}.
$\gamma = 1.4$ for air.
x is distance the wave has traveled along the cylindrical tube in m.

Equation (9.85) breaks down when the second-harmonic distortion becomes large, and a more complicated expression, not given here, must be used.

In the case of an exponential horn, the amplitude of the fundamental decreases as the wave travels away from the throat, so that the second-harmonic distortion does not increase linearly with distance. Near the throat it increases about that given by Eq. (9.85), but near the mouth the pressure amplitude of the fundamental is usually so low that very little additional distortion occurs.

The distortion introduced into a sound wave after it has traveled a distance x down an exponential horn for the case of a constant power supplied to unit area of the throat is found as follows.

Differentiate both sides of Eq. (9.85) with respect to x, so as to obtain the rate of change in p_2 with x for a constant p_1. Call this equation (9.85a).