18.7 We suppose the man's ears are at the same level as the lower speaker. Sound from the upper speaker is delayed by traveling the extra distance $\sqrt{L^2 + d^2} - L$.

He hears a minimum when this is $(2n - 1)\lambda/2$ with $n = 1, 2, 3, \ldots$

Then, $\sqrt{L^2 + d^2} - L = (n - 1/2)v/f$

$$\sqrt{L^2 + d^2} = (n - 1/2)v/f + L$$

$$L^2 + d^2 = (n - 1/2)^2 v^2/f^2 + L^2 + 2(n - 1/2)vL/f$$

$$L = \frac{d^2 - (n - 1/2)^2 v^2/f^2}{2(n - 1/2)v/f} \qquad n = 1, 2, 3, \ldots$$

This will give us the answer to (b). The path difference starts from nearly zero when the man is very far away and increases to d when $L = 0$. The number of minima he hears is the greatest integer solution to $d \geq (n - 1/2)\, v/f$

n = greatest integer $\leq df/v + 1/2$

(a) $df/v + \frac{1}{2} = (4.00\text{ m})(200/\text{s})/330\text{ m/s} + \frac{1}{2} = 2.92$

He hears **two** minima.

(b) With $n = 1$,

$$L = \frac{d^2 - (1/2)^2 v^2/f^2}{2(1/2)v/f} = \frac{(4.00\text{ m})^2 - (330\text{ m/s})^2/4(200/\text{s})^2}{(330\text{ m/s})/200/\text{s}}$$

$$L = \boxed{9.28\text{ m}}$$

with $n = 2$

$$L = \frac{d^2 - (3/2)^2 v^2/f^2}{2(3/2)v/f} = \boxed{1.99\text{ m}}$$

18.8 Suppose the man's ears are at the same level as the lower speaker. Sound from the upper speaker is delayed by traveling the extra distance $\Delta r = \sqrt{L^2 + d^2} - L$.

He hears a minimum when

$$\Delta r = (2n - 1)\left(\frac{\lambda}{2}\right) \text{ with } n = 1, 2, 3, \ldots$$

Then, $\sqrt{L^2 + d^2} - L = (n - 1/2)(v/f)$

$$\sqrt{L^2 + d^2} = (n - 1/2)(v/f) + L$$

$$L^2 + d^2 = (n - 1/2)^2(v/f)^2 + 2(n - 1/2)(v/f)L + L^2 \qquad (1)$$

Equation 1 gives the distances from the lower speaker at which the man will hear a minimum. The path difference Δr starts from nearly zero when the man is very far away and increases to d when $L = 0$.

(a) The number of minima he hears is the greatest integer value for which $L \geq 0$. This is the same as the greatest integer solution to $d \geq (n - 1/2)(v/f)$, or

$$\boxed{\text{number of minima heard} = n_{max} = \text{greatest integer} \leq d(f/v) + 1/2}$$

(b) From Equation 1, the distances at which minima occur are given by

$$\boxed{L_n = \frac{d^2 - (n - 1/2)^2(v/f)^2}{2(n - 1/2)(v/f)} \text{ where } n = 1, 2, \ldots, n_{max}}$$

18.9 $y = (1.50 \text{ m}) \sin(0.400x) \cos(200t) = 2A_0 \sin kx \cos \omega t$

Therefore,

$$k = \frac{2\pi}{\lambda} = 0.400 \frac{\text{rad}}{\text{m}} \qquad \lambda = \frac{2\pi}{0.400 \text{ rad/m}} = \boxed{15.7 \text{ m}}$$

and $\omega = 2\pi f$, so $f = \dfrac{\omega}{2\pi} = \dfrac{200 \text{ rad/s}}{2\pi \text{ rad}} = \boxed{31.8 \text{ Hz}}$

The speed of waves in the medium is

$$v = \lambda f = \frac{\lambda}{2\pi} 2\pi f = \frac{\omega}{k} = \frac{200 \text{ rad/s}}{0.400 \text{ rad/m}} = \boxed{500 \text{ m/s}}$$

18.11 The facing speakers produce a standing wave in the space between them, with the spacing between nodes being

$$d_{NN} = \frac{\lambda}{2} = \frac{v}{2f} = \frac{343 \text{ m/s}}{2(800 \text{ s}^{-1})} = 0.214 \text{ m}$$

If the speakers vibrate in phase, the point halfway between them is an

antinode, at $\dfrac{1.25 \text{ m}}{2} = 0.625$ m from either speaker.

Then there is a node at

$$0.625 \text{ m} - \frac{0.214 \text{ m}}{2} = \boxed{0.518 \text{ m}}, \text{ a node at}$$

$$0.518 \text{ m} - 0.214 \text{ m} = \boxed{0.303 \text{ m}}, \text{ a node at}$$

$$0.303 \text{ m} - 0.214 \text{ m} = \boxed{0.0891 \text{ m}}, \text{ a node at}$$

$$0.518 \text{ m} + 0.214 \text{ m} = \boxed{0.732 \text{ m}}, \text{ a node at}$$

$$0.732 \text{ m} + 0.214 \text{ m} = \boxed{0.947 \text{ m}}, \text{ and a node at}$$

$$0.947 \text{ m} + 0.214 \text{ m} = \boxed{1.16 \text{ m}} \text{ from either speaker}$$

18.21 $L = 60.0 \text{ cm} = 0.600 \text{ m}$ $\quad T = 50.0 \text{ N}$ $\quad \mu = 0.100 \text{ g/cm} = 0.0100 \text{ kg/m}$

$$f_n = \frac{nv}{2L}$$

where

$$v = \left(\frac{T}{\mu}\right)^{1/2} = 70.7 \text{ m/s}$$

$$f_n = n\left(\frac{70.7}{1.20}\right) = 58.9n = 20{,}000 \text{ Hz}$$

Largest $n = 339 \Rightarrow f = \boxed{19.976 \text{ kHz}}$

*18.28 The distance between adjacent nodes is one-quarter of the circumference.

$$d_{NN} = d_{AA} = \frac{\lambda}{2} = \frac{20.0 \text{ cm}}{4} = 5.00 \text{ cm}$$

so $\lambda = 10.0$ cm and $f = \frac{v}{\lambda} = \frac{900 \text{ m/s}}{0.100 \text{ m}} = 9000 \text{ Hz} = \boxed{9.00 \text{ kHz}}$

The singer must match this frequency quite precisely for some interval of time to feed enough energy into the glass to crack it.

*18.45 (a) For the fundamental mode of an open tube,

$$L = \frac{\lambda}{2} = \frac{v}{2f} = \frac{343 \text{ m/s}}{2(880 \text{ s}^{-1})} = \boxed{0.195 \text{ m}}$$

(b) $v = 331 \text{ m/s} \sqrt{1 + \frac{(-5.00)}{273}} = 328 \text{ m/s}$

We ignore the thermal expansion of the metal.

$$f = \frac{v}{\lambda} = \frac{v}{2L} = \frac{328 \text{ m/s}}{2(0.195 \text{ m})} = \boxed{841 \text{ Hz}}$$

The flute is flat by a semitone.