ACOUSTICS QUALIFYING EXAM

FALL 2011

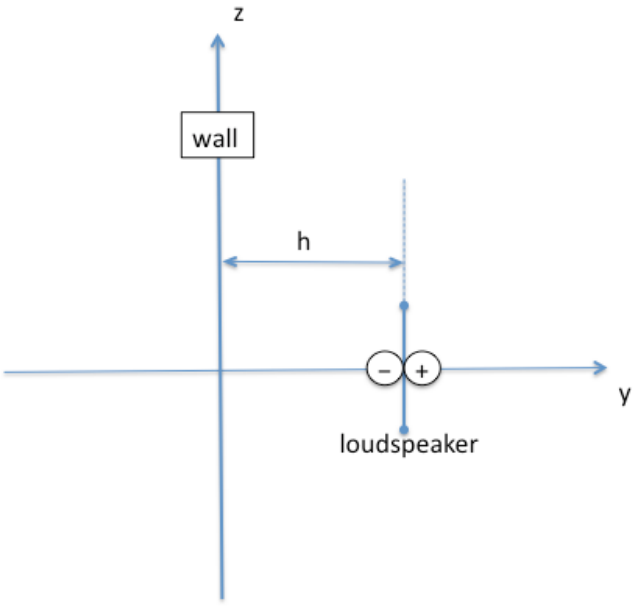
SUBMIT SOLUTIONS FOR ANY 3 OF THE FOLLOWING 4 PROBLEMS.

Problem 1

An unbaffled loudspeaker is first placed far from the floor and close to a wall with its face parallel to the surface as shown in the FIGURE 1 below. Next the same loudspeaker is placed far from any walls and close to the floor with its face perpendicular to the surface as shown in FIGURE 2 below. Assume that this loudspeaker can be modeled as a time-harmonic point dipole. For each of these two arrangements, evaluate the following cases:

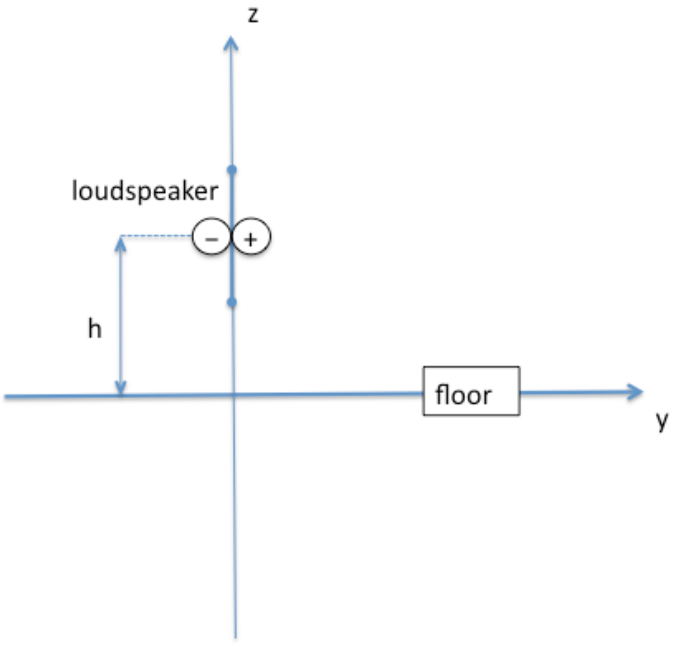
(a) The surface is a rigid surface. Find a general expression for pressure in the far field of the loudspeaker. Simplify this expression for the case of the loudspeaker very near the surface, sketch a polar plot of the acoustic radiation pattern, and describe the effect of the surface on the acoustic field. Which arrangement do you think is better and why?

(b) The surface is a pressure-release surface. Find a general expression for pressure in the far field of the loudspeaker. Simplify this expression for the case of the loudspeaker very near the surface, sketch a polar plot of the acoustic radiation pattern, and describe the effect of the surface on the acoustic field. Which arrangement do you think is better for this case? Why?



← FIGURE 1.

FIGURE 2. →

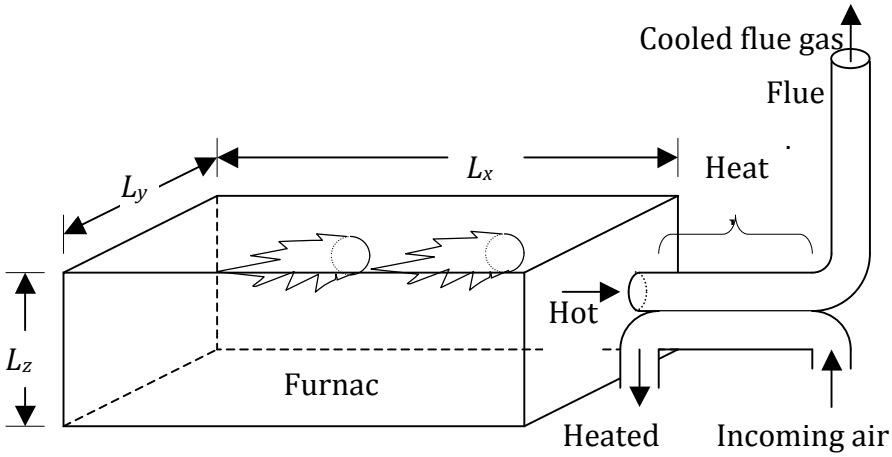


Problem 2

A new over-fire furnace is found to produce excessive amounts of tonal noise at approximately 55 Hz when it operates at 1900 K. The furnace's interior has dimensions of L_x = 8 m by L_y = 4.0 m by L_z = 2.0 m. The flue from the furnace is a round pipe 0.30 m in diameter and 12.50 m long attached to the end of the furnace (as shown). Near the furnace, the flue pipe is part of a counter-flow heat exchanger. Both ends of the flue pipe are acoustic open ends. Heat exchange between the incoming and outgoing gases causes the flue pipe gas to be on average 700 K cooler than the furnace gas. The natural gas burners that heat the furnace are known to unintentionally amplify sound in the 10 to 100 Hz range because of gas-mixing and combustion instabilities. You are hired as an acoustic consultant to explain what's happening and to prioritize action on possible solutions.

[Hint: Compare the natural frequencies of the furnace and pipe.]

a) Assuming the various hot gases are the same as air, determine the speed of sound in the furnace and flue pipe.



b) Using waveform sketches, mode numbers, and/or words, describe what is happening when the 55 Hz noise is present.

c) To reduce complaints about the tonal noise, the following noise abatement possibilities are considered.

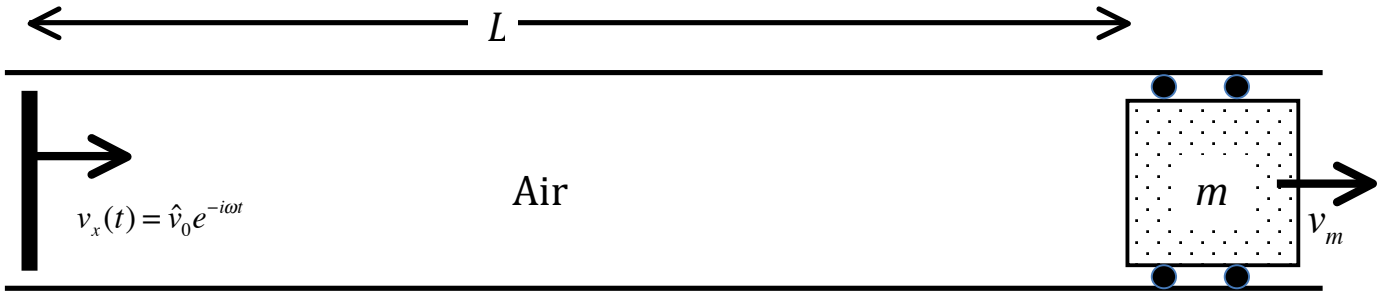
i) An inline valve that produces acoustic resistance when partially open may be placed halfway long the flue pipe.

ii) The flue pipe inlet may be moved to the center of one of the long sides of the furnace.

iii) A capped side-branch may be added to the flue pipe anywhere along its length.

iv) Ear plugs can be issued to the furnace operators and all nearby personnel.

Based on acoustic considerations, mention at least one positive and one negative implication for each of these possibilities, and rank them from most to least likely to be successful and adopted.



Rigid Wall Tube

Problem 3

A rigid-walled air -filled square waveguide of length *L* and cross sectional area *A* is terminated at one end (*x*=0) by a piston and at the other end (*x*=*L*) by a steel block of mass *m* , which is free to move in the *x* direction. Assume that both the piston and the mass effectively fill the cross section of the tube and that the motion-induced pressure on the far side of the block can be ignored. The piston driving the tube has velocity

$v_x(t) = \hat{v}_0 e^{-i\omega t}$.

For all frequencies of interest assume that $\lambda^2 >> A$ and $\rho c << m\omega / A$.

In terms of these parameters:

a) Find a general expression for the resonance frequencies of this system.

b) Show that the lowest mode corresponds to the resonance of an "air spring" of length *L* and cross section *A*, resonating with the mass *m*. [**HINT:** the bulk modulus of air i**s** ρc^2 **]**

c) Show that the remaining resonances are close to those of a waveguide of length *L* with a v_x = 0 termination.

Problem 4

At 2000 Hz, the sound pressure level on axis at 50 m is 47 dB (*re* 20 μPa) for a plane circular piston in an infinite baffle. Assume that the piston operates in air (c = 343 m/s; ρ_0 =1.206 kg/m^3) and the radius of the piston is 1 m. You know that $j_{1,1} = 3.83$ for the Bessel Function of the first kind, $J_m(j_{mn}) = 0$.

Based on the relationship that $p(r,\theta,t) = j\rho_0 c \frac{U_0}{\lambda} \int_S \frac{1}{r'} e^{j(\omega t - kr')} dS$, find the following:

a) What is the rms speed of the piston?

b) What is the smallest angle at which the pressure amplitude in the far field is equal to zero?

c) If the frequency were doubled while keeping the velocity amplitude of the piston constant, what would be the dB change in sound pressure level on the axis at 50 m?