M.E. Ph.D. Qualifier Exam
Fall Semester 2004

GEORGIA INSTITUTE OF TECHNOLOGY

The George W. Woodruff
School of Mechanical Engineering

Ph.D. Qualifiers Exam - Fall Semester 2004

ACOUSTICS

EXAM AREA

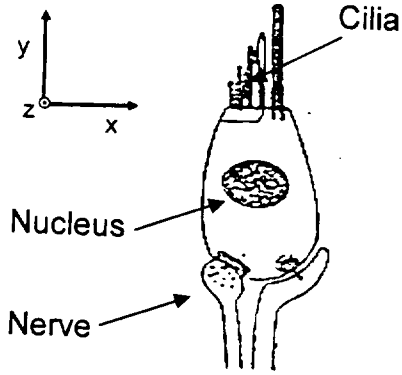
Assigned Number **(DO NOT SIGN YOUR NAME)**

* Please sign your **name** on the back of this page —

PhD Qualifying Examination in Acoustics

Monday Oct 25th 2004

Two-hours, closed-book . Answer all parts of all three questions.



1. The sensory hair cell (illustrated above) is the universal mechanosensor for all vertebrates. As such, in addition to being the sensor for linear and rotational acceleration, it is the receptor for hearing for mammals, reptiles, birds and fish. The sensory hair cell is believed to respond to a particular component of the instantaneous shear strain in the fluid where it is located. In some fish, aligned hair cells exist which have no apparent auxiliary hearing-related structures to enhance the local fluid shear.

For a hair cell oriented as shown with respect to a Cartesian coordinate system, its response $\Phi(t)$ is proportional to the x-y shear strain of the fluid where it is located. That is,

$$\Phi(t) \propto \frac{1}{2}\left(\frac{\partial \xi_y}{\partial x} + \frac{\partial \xi_x}{\partial y}\right)$$

where $\vec{\xi}$ is the fluid particle displacement vector. A plane harmonic acoustic wave

$$p = \hat{p}_0 e^{i\vec{k}\cdot\vec{R}-i\omega t}$$

wavevector $\vec{k}$ is incident on the fluid.

a) What is the angular dependence of the hair cell response to this wave? That is, how does Φ depend on spherical coordinate angles θ and ϕ which define direction of the incident wave?

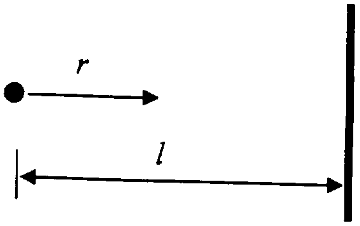
b) Sketch the response in the x-y plane (in polar coordinates)

c) What is the response in the x-z plane?

d) The threshold of hearing for a goldfish at 500Hz is 60dB re 1μPa. If this detection was accomplished through the mechanism described above, what is the size of the strain that the fish is responding to?

2. Consider a source a distance l away from a plane surface, as depicted below. The frequency-independent reflection coefficient for the plane is

$$R = |R| e^{j\varphi}$$



The source produces a sound field

$$p = \frac{\hat{p}}{r} e^{j(\omega t - kr)}$$

a) Using the method of images, determine the rms pressure as a function of distance r along the perpendicular between the source and the plane, with r measured from the source, and assuming that the source is emitting a pure tone of frequency f_c.

b) Determine the rms pressure as above, but now assume that the source is emitting a broadband signal of bandwidth B centered on f_c. Note that the image source is NOT incoherent in this case.

c) Discuss the significance of the results of parts a and b, with particular attention to pure tone and broadband measurements approaching a reflecting plane.

3. Consider the case where the motion of a baffled circular piston of radius a is blocked over concentric zones as shown below. The normal velocity of the source $v_n(r,t)$ is given as

$$v_n(r,t) = \begin{cases} v_o \cos(\omega t) & \text{for } r_1 > r > 0,\ r_3 > r > r_2 \text{ and } a > r > r_4 \\ 0 & \text{elsewhere} \end{cases}$$

a) Derive an expression for the pressure generated by this source on the symmetry axis, i.e. the z-axis.

b) Given the piston radius, a = 7.5 λ, find expressions for the radii (r_1 through r_4) of the concentric blocking zones (Fresnel plate zones) so that the acoustic pressure magnitude at z_o = 10 λ is as large as possible.

c) Show that the resulting pressure at z_o = 10 λ is 3 times larger than the pressure which would be generated by an "unblocked" piston of the same size.