Mechanical Processing in Internally Coupled Ears

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TMP Thesis Defence
July 5, 2013

Auditory Systems

Independent Ears

Eustachian tubes typically very narrow.

Effectively independent eardrum vibrations.

Coupled Ears

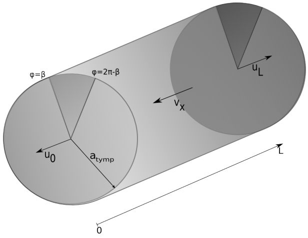
Eardrums connected through wide eustachian tubes and a large mouth cavity.

Eardrums vibrations influence eachother.

Advantages of Low Frequency Hearing

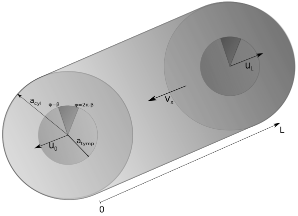
Mouth Cavity

Previous Model



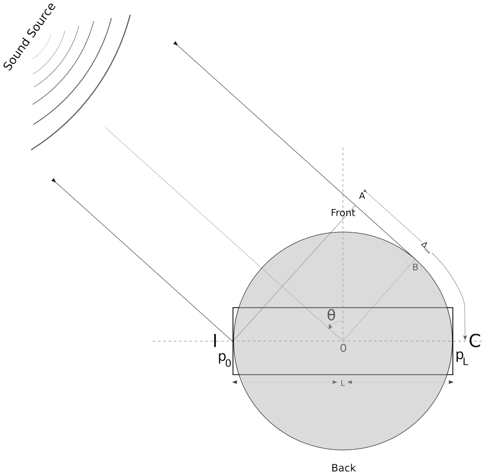
- $V_{\mathrm{cyl}} = \pi a_{\mathrm{tymp}}^2 L$

Our Model



- V_{cyl} based on anatomical data.
- $a_{\mathrm{cyl}} = \sqrt{V_{\mathrm{cyl}}/\pi L}$

Acoustic Head Model



- I - Ipsilateral C - Contralateral
- Sound source far enough away from the animal ("Infinity").
- Phase difference between sound at both ears - $\Delta = 1.5kL\sin\theta$.
- No appreciable amplitude difference, $|p_0| = |p_L|$.

Cavity Pressure

3D Wave Equation

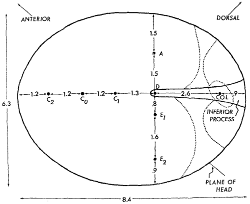
$$\frac{1}{c^2}\partial_t^2 p(x,r,\phi,t) = \frac{1}{r}\frac{\partial}{\partial r}\left(r\frac{\partial p(x,r,\phi,t)}{\partial r}\right) + \frac{1}{r^2}\frac{\partial p(x,r,\phi,t)}{\partial \phi^2} + \frac{\partial p(x,r,\phi,t)}{\partial x^2} \tag{1}$$

No-penetration at all solid boundaries

$$-j\rho\omega\mathbf{v} = \nabla p(x,r,\phi;t) = 0 \tag{2}$$

Eardrum

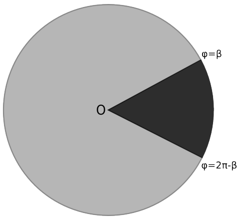
Sketch of a Tokay eardrum as seen from the outside[a].



COL - approximate position opposite the extracolumella insertion.

[a] G. A. Manley, "The middle ear of the tokay gecko," *Journal of Comparative Physiology*, vol. 81, no. 3, pp. 239–250, 1972

The ICE eardrum.



Extracolumella (dark) - rigid, stationary.

Tympanum - assumed linear elastic.

Rigidly clamped at the boundaries ($r = a_{\text{tymp}}$ and $\phi = \beta,\ 2\pi - \beta$)

Membrane Vibrations

Membrane EOM

$$-\partial_t^2 u(r,\phi;t) - 2\alpha\partial_t u(r,\phi;t) + c_M^2 \nabla^2 u(r,\phi;t) = \frac{1}{\rho_m d}\Psi(r,\phi;t) \tag{3}$$

Evaluation

Conclusion

Thank You