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Modeling Impact of Seismic Sound on Marine Invertebrates

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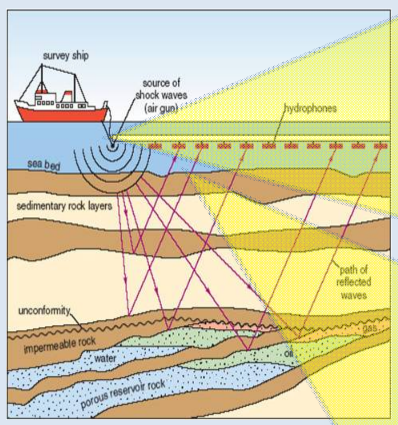
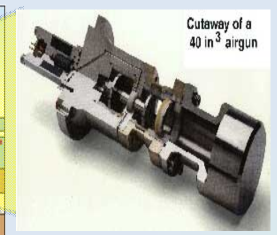
Introduction and Motivation

The effects of seismic testing on cetaceans have been extensively studied and measures have already been adopted to mitigate them. The effects on invertebrates are less well understood. Invertebrates do not have internal gas-filled cavities, so it is thought that they should be less vulnerable. However, they are unable to leave the area during a seismic test.





Air gun

Snow Crab, *Chionoecetes opilio*

This is a theoretical study, using classical acoustics to predict physical motions of a crab's interior during a seismic test.

Theoretical Model

Source

- Multiple regular or GI airguns

Pathway

- Include reflections from water surface
- Bottom neglected

Target

- Crab approximated as spherical
- Interior modeled as a uniform, easily sheared solid

Air gun modeling

As an air gun fires it suddenly releases a bubble of air that is at high pressure. This forms a bubble which rapidly expands and then oscillates about an equilibrium radius (this process is somewhat modified in "G.I. guns"). The expansion and subsequent oscillation can be modeled using the Kirkwood-Bethe Equation:

Acceleration of Bubble wall

Forces Acting on Bubble Wall

$$\ddot{R} = \frac{H\left(1-\frac{\dot{R}}{C}\right) + \frac{R}{C}\dot{H}\left(1-\frac{\dot{R}}{C}\right) - \frac{3}{2}\dot{R}^2\left(1-\frac{\dot{R}}{3C}\right) - \alpha\dot{R}}{R\left(1-\frac{\dot{R}}{C}\right)}$$

Enthalpy at bubble wall: related to the ambient pressure (affected by gun-gun interaction).

Empirical damping constant

This, combined with an equation of state for water, allows us to find the radius vs. time for the bubble. Knowledge of the bubble dynamics allows the far field pressure signal can be determined from

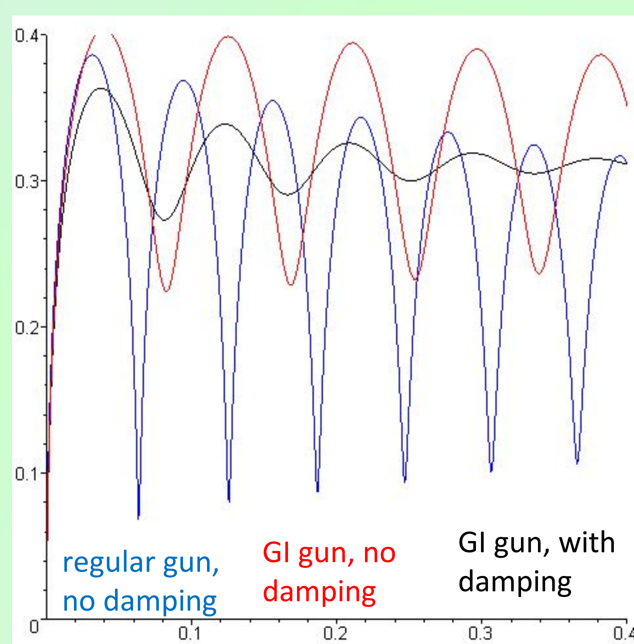
Far field pressure

Water density

Distance from source

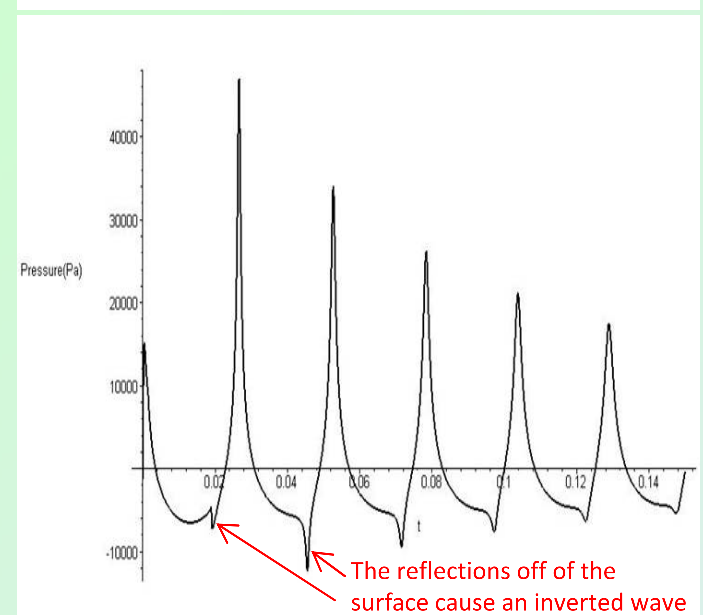
Equilibrium hydrostatic pressure

$$p_f - p_\infty = \frac{\rho R}{r}\left(H + \frac{\dot{R}^2}{2}\right)$$



Bubble radii vs. time for three cases

Deviation of Far Field Pressure

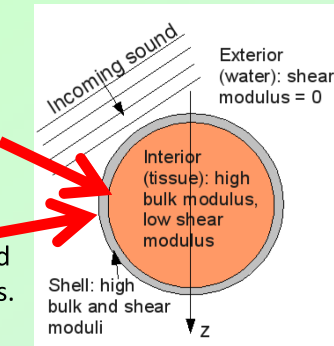


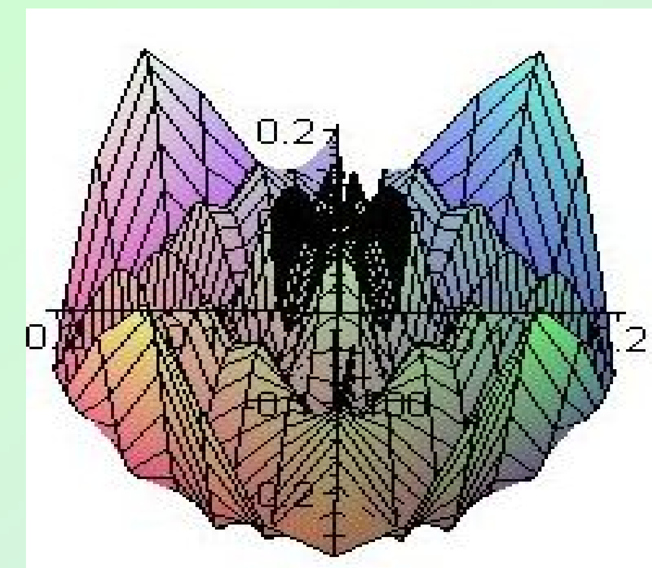
Modeling the crab

The interaction of the incoming sound from the guns with the crab is treated as a boundary value problem of the homogeneous Helmholtz wave equation

Solid-solid boundary: displacement and stress continuous

Liquid-solid boundary: normal displacement and normal stress continuous. Tangential stress is zero.





Radial displacement in a vertical cross section through the crab for two waves passing through the crab at right angles to each other

Preliminary conclusions

The displacements we find in the interior of the crab are lower than what is thought to be likely to cause damage. However, for an organ embedded in other tissues with similar elastic moduli we find displacements at the boundary of the organ that may be sufficient to cause damage.

References:

Landro, M. 1992. "Modelling of GI Gun Signatures", *Geophys. Prosp.*, **40**, 721, (1992).

Stanton, T. "Sound scattering by spherical and elongated shelled bodies", *J. Acoust. Soc. Am.*, **88**, 1619, (1990).