Natural Frequencies of Immersed Beams

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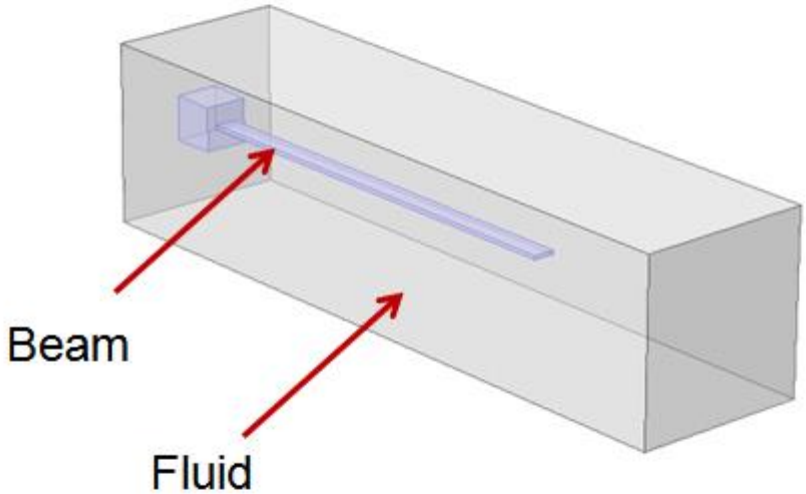
Today, we invite guest blogger Nagi Elabbasi of Veryst Engineering to share a modeling example of immersed beams.

When thin structures such as beams, plates, or shells are immersed in a fluid, their natural frequencies are reduced. The fluid also affects their mode shapes and is a source of damping. This phenomenon affects structures across a wide range of industries and sizes, from micro-scale structures (e.g. MEMS actuators) to larger structures (e.g. ships).

The Model: An Immersed Cantilever Beam

Today, we will take a look at a model of a cantilever beam immersed in a fluid:



An approximate analytical solution of the form shown below is frequently used to estimate the natural frequencies of the immersed beam. This is estimated based on the *structure-only* natural frequencies, beam geometry, and the ratio of fluid-to-beam densities. The analytical expression approximately accounts for the added mass of the fluid that is displaced by the beam. It does not account for viscous effects.

$$\omega_{fluid} = \frac{\omega_{vacuum}}{\sqrt{1 + \frac{\pi}{4}\frac{b}{h}\frac{\rho_{fluid}}{\rho_{beam}}\Gamma}}$$

Correction factor

Density ratio

Beam aspect ratio

A Multiphysics Approach to Determining Natural Frequencies and Mode Shapes

We at [Veryst Engineering](#) used COMSOL Multiphysics to determine the natural frequencies and mode shapes of an immersed cantilever beam. Then, we compared the results with the analytical approximation.

We set up the problem as a coupled acoustic-structure eigenvalue analysis. To account for the mass of the fluid, we selected a pressure acoustics formulation, and we accounted for damping due to fluid viscosity by including a viscous loss term. We assumed the fluid space to be sealed. The COMSOL software automatically detects the solid-fluid boundary and applies the necessary boundary conditions at the solid-fluid interface.

Solution

Below, you can see a table with the first and fourth natural frequencies (in kHz) of beams in vacuum, air, and water:

	In Vacuum	In Air	In Water	In Water (Analytical)
First mode	81.9	81.9	65.9	67.1
Fourth mode	513.5	513.3	418.5	422.2

As expected, the results show that air has a minor effect on the beam, while water reduces the lowest natural frequencies of the beam by about 20%. Also shown in the table is the analytical estimate for a beam immersed in water. The analytical estimate is close to the COMSOL Multiphysics prediction for this relatively standard beam configuration.

Next, we can have a look at a couple of animations of our results.

The first animation depicts the fourth mode of deformation for a beam immersed in water:

Fourth mode shape of cantilever beam immersed in water.

The second animation demonstrates fluid pressure contours and fluid velocity arrow plots at a section along the beam, again for the fourth natural frequency of the beam.

Velocity and pressure contours for fourth beam natural frequency.

This modeling example involved a simple cantilever to illustrate the concept. However, the coupled structural-acoustic modeling approach used is also applicable to more realistic geometries, such as ship hulls and MEMS actuators.

About the Guest Author

Nagi Elabbasi, PhD, is a Managing Engineer at Veryst Engineering LLC. Nagi's primary area of expertise is modeling and simulation of multiphysics systems. He has extensive experience in finite element modeling of structural, CFD, heat transfer, and coupled systems, including fluid-structure interaction, conjugate heat transfer, and structural-acoustic coupling. Veryst Engineering provides services in product development, material testing and modeling, and failure analysis, and is a member of the COMSOL Certified Consultant program.