Parametric Investigation of the Common Geometry Shapes for Added Mass Calculation

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Abstract

Fluid-Structure Interaction (FSI) occurs due to the interaction of multiple continuum fields. The added mass loading, hydrodynamic mass is one of the most common FSI phenomenon. Basically the added mass effect is when a structure acts as if it were heavier by an added amount while being overwhelmed by an external continuum. In order to see how structures are experiencing the added mass loading effect differently by varying their geometry, it is necessary to investigate the effect of each dimension of its geometry by comparing the numerical values of added mass.

Accordingly, this work is aimed to demonstrate how variation of geometries' parameters would affect the fluid loading effect in water. To cope with this, three-dimensional objects are places in a water medium. First, a solid cylinder, a solid sphere, and a rectangular cantilever beam are studied through the time harmonic analysis by applying acoustic wave to the acoustic fluid medium. More specifically, background acoustic pressure has been used to simulate an incident plane wave which excites the structure in water. Secondly, the inlet velocity and outlet pressure gradient are applied for fluid structure interaction investigation in fluid domain. In this paper, two hydrodynamic mass equations from the literature are used to estimate the analytical added mass value for each freely placed sphere and cylinder when the medium is accelerated at a certain velocity. Moreover, the equations of flexural and torsional resonant frequencies of a rectangular cantilever beam from the literature have been used to evaluate the analytical amount of virtual mass when an incident plane wave excites the structure in acoustic fluid medium. The added mass values of the structures obtained from both acoustic-structure and fluid-structure analyses are compared to each other as well as with the analytical values.

Finally, the obtained result shows how varying any of the geometries' parameters would result in different virtual mass. In COMSOL Multiphysics, the Acoustic and Fluid-Structure Interaction physics have been implemented through a frequency domain analysis and a transient analysis, respectively, which consequently lead to the process of calculation of added mass. The conclusion of this work will simplify calculation of the added mass when designing/analyzing underwater sensors/transducers, which usually takes lengthy process and time.

Reference

[1] F. Sotiropoulos, and X. Yang, " Immersed Boundary Methods for Simulating Fluid–Structure Interaction," Progress in Aerospace Sciences, 65, pp.1-21, (2013).

[2] J. E. Sader, and C. A. Van Eysden, "Frequency Response of Cantilever Beams Immersed in Compressible Fluids with Applications to the Atomic Force Microscope," Applied Physics, 109, pp. 1-8, (2009).

[3] H. Liu, and H. Li, and Qin, "Added Mass Matrix Estimation of Beams Partially Immersed in Water using Measured Dynamic Responses," Sound and Vibration, 333, pp. 5004-50017, (2014).

[4] X. Li, and A. Tang, and L. Xi, "Vibration of a Rayleigh Cantilever Beam with Axial Force and Tip Mass," Constructional Steel Research, 80, pp. 15–22, (2013).

[5] F. Wang, and X. Zhao," Size Dependant Dynamics of Cantilever Beams Immersed in Viscous Fluid," Microscopy Society of America, 15 (2), pp.1134-1136, (2009).

[6] P. Causin, and J.F. Gerebau, and F. Nobile, "Added-Mass Effect in the Design of Partitioned Algorithms for Fluid-Structure Problem," Computer Methods in Applied Mechanics and Engineering, 194, pp. 4506-4527, (2004).

[7] J. H. Wu, and A. Q. Liu, and H. L. Chen, "Exact Solution for Free-Vibration Analysis of Rectangular Plates Using Bessel function," Journal of Applied Mechanics, 74, pp. 1247-1251, (2007).

[8] J. Dutka, "On the early history of Bessel functions," Archive for History of Exact Sciences, 49 (2), pp. 105-134, (1995).

[9] M. Webster, and B. Patchin, and M. Turner, and J. Wikswo, and J. Waters, "Kater's Pendulum," pp. 1-7, (2003).

[10] D. Candela, and K. M. Martini, and R.V. Krotkov, and K. H. Langley, "Bessel's Improved Kater Pendulum in the Teaching Lab," American Association of Physics Teachers, 69 (6), pp.714-720, (2001).

[11] R. N. Govardhan, and C. H. K. Williamson, "Vortex-Induced Vibrations of a sphere," Journal of Fluid Mechanics, 531, pp. 11-47, (2005).

[12] R. K. Singhal, and W. Guan, and K. Williams, "Modal Analysis of a Thick Cylinder," pp. 1-7, (2003).

[13] E. Da Lozzo, and F. Auricchio, and G. M. Calvi, "Added Mass Model for Vertical Circular Cylinder Immersed in water," 15WCEE, Earthquake Engineering, Lisbon, pp. 1-10, (2012).

[14] W. H. Chu,Tech. Rep. No. 2, DTMB, Contract NObs-86396X, Southwest Research Institute, San Antonio, Texas, (1963).

[15] F. M. White, Fluid Mechanics, 5th ed., McGraw-Hill, New York, NY, Chap.8. pp. 566-568, (2003)

Figures used in the abstract

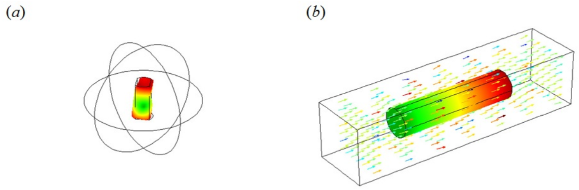


Figure 1: Post-processing plot of surface total displacement for a slid cylinder in (a) Acoustic Fluid Domain, and (b) Fluid Domain.

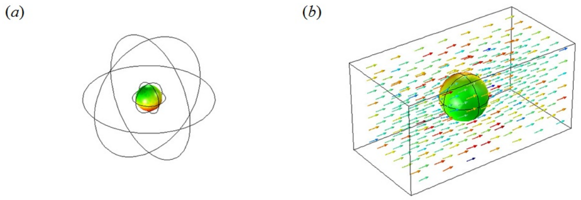
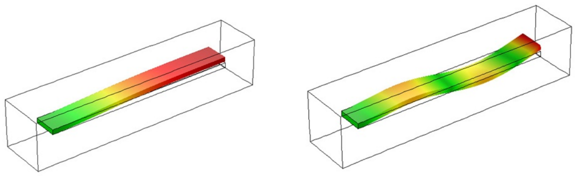


Figure 2: Post-processing plots of surface total displacement for a solid sphere in (a) Acoustic Fluid Domain, and (b) Fluid Domain.



(a) First mode (10 Hz)

(b) Second mode (60 Hz)

Figure 3: (a) First, and (b) second mode shapes of the rectangular cantilever beam

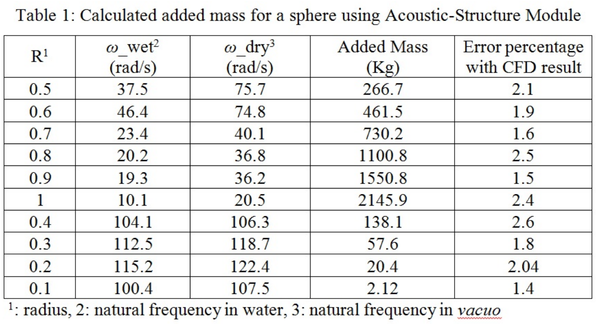


Table 1: Calculated added mass for a sphere using Acoustic-Structure Module

R[1]	ω_wet[2] (rad/s)	ω_dry[3] (rad/s)	Added Mass (Kg)	Error percentage with CFD result
0.5	37.5	75.7	266.7	2.1
0.6	46.4	74.8	461.5	1.9
0.7	23.4	40.1	730.2	1.6
0.8	20.2	36.8	1100.8	2.5
0.9	19.3	36.2	1550.8	1.5
1	10.1	20.5	2145.9	2.4
0.4	104.1	106.3	138.1	2.6
0.3	112.5	118.7	57.6	1.8
0.2	115.2	122.4	20.4	2.04
0.1	100.4	107.5	2.12	1.4

[1]: radius, 2: natural frequency in water, 3: natural frequency in *vacuo*

Figure 4: Calculated added mass for a sphere using Acoustic-Structure Module