PHYSICAL MATH SEMINAR

From Pressure Impulse to Water Hammer: A Strouhal Number Framework for Impact-Driven Liquids

Yoshiyuki Tagawa

(Tokyo University of Agriculture and Technology)

ABSTRACT:

When a liquid is abruptly accelerated, its pressure field has traditionally been analyzed in two distinct limits: the incompressible pressure impulse theory, based on Laplace's equation for potential flow, and the compressible water-hammer theory, derived from the wave equation and the method of characteristics. Yet, the intermediate regime connecting these limits has remained unclear.

In this talk, I will present recent experiments on liquid columns under short-time acceleration, demonstrating that the Strouhal number, St=ct/L, measuring the ratio of acoustic to acceleration time scales, unifies these classical approaches. For $St \ll 1$, the pressure field is governed by an elliptic Laplace framework; for $St \gg 1$, by a hyperbolic wave framework; and in the intermediate regime St=O(1), we reveal a smooth transition connecting the two. A simple wavefront-thickness analysis explains the observed fluctuations, consistent across diverse liquids and even hydrogels.

Finally, I will show how this perspective extends beyond fundamental dynamics: to cavitation onset in accelerating liquids [Pan et al., PNAS 114, 8470–8474 (2017)], granular jets, and biomedical microjets, including liposome generation by laser-induced jets [Jiajue et al., Lab on a Chip 25, 2644–2653 (2025)] and tissue interaction in needle-free injection [Miyazaki et al., Sci. Rep. 11, 14544 (2021)]. These examples highlight how a unified Strouhal framework connects elliptic and hyperbolic mathematics with real-world applications.

REFERENCES:

Kurihara, C., Kiyama, A. & Tagawa, Y. J. Fluid Mech. 1003, A20 (2025).
Kiyama, A., Tagawa, Y., Ando, K. & Kameda, M. J. Fluid Mech. 787, 224–236 (2016).
Gordillo, J. M., Onuki, H. & Tagawa, Y. J. Fluid Mech. 894, A3 (2020).
Watanabe, H., Kusuno, H. & Tagawa, Y. Int. J. Multiphase Flow 193, 105348 (2025).
Pan, Z., Kiyama, A., Tagawa, Y., et al. PNAS 114, 8470–8474 (2017).
Miyazaki, Y., Usawa, M., Kawai, S., Yee, J., Muto, M. & Tagawa, Y. Sci. Rep. 11, 14544 (2021).
Jiajue, J., Kawai, S., Takagi, R., Koiwai, K., Kawano, R. & Tagawa, Y. Lab on a Chip 25, 2644–2653 (2025).

TUESDAY, SEPTEMBER 23, 2025

2:30 PM – 3:30 PM

Building 2, Room 449

MIT MATHEMATICS

https://math.mit.edu/pms/