WEEK 8

Article: Mahkam *et.al.*, A multiorifice acoustic microrobot for boundaryfree multimodal 3D swimming, *PNAS*, 2025.

QUESTIONS 8A

1. The article states that the resonance frequency depends strongly on the diameter of the trapped bubble but not on the viscosity. What is the underlying physical principle for this dependence, and can the relationship be derived analytically or modeled theoretically? How do fluid properties (e.g., density, viscosity, and acoustic impedance) impact the locomotion performance of the microrobot, given their influence on sound wave propagation and bubble resonance?

2. It is stated that the placement and size of the orifice ensure asymmetry, which is necessary for propulsion. How was the number of orifices determined? Could we add more holes compared to the existing one while maintaining asymmetry to generate more thrust? In what specific ways does adjusting the orifice size ratio and their tangential arrangement, especially with a 90-degree phase difference, enable frequency-dependent multimodal locomotion through flow asymmetry? What would happen if the orifices were all the same size and placed symmetrically? Would the robot still be able to move?

3. How does the swimming speed vary with the input voltage at a fixed sound frequency (Figure 2E) and what does this imply about the relationship between acoustic energy input and propulsion efficiency? The paper mentions speeds up to 300 body lengths per second. What about the acoustic power required to propel a microrobot of a given size at such a speed in a viscous fluid?

4. In biological environments like the venous system, local fluid pressure can drop near zero. Considering the Rayleigh-Plesset equation (Eq. S9 in the appendix), what impact does the pressure variation have along a canal when estimating a bubble's resonance frequency? Can it be neglected? If not, what qualitative impact does it have on the resonance behavior and swimming modes?

5. What is optoacoustic (OA) imaging? How does coating the microrobot with a 50 nm-thick layer of gold enables OA tracking? How does the physical structure of the robot (e.g., gold layer thickness, shell curvature, bubble shape) affect imaging contrast, and what trade-offs exist between imaging performance and locomotion dynamics?