WEEK 7

Article: Hong *et.al.*, A Wireless flow-- powered miniature robot capable of traversing tubular structures, *Science Robotics*, 2024.

QUESTIONS 7b

1. The gear reduction ratio of 2018:1 is pretty impressive for this size, but how does the miniature gearbox balance between high-speed, low-torque impeller rotation and the torque requirements of the robot's wheels, and what limitations does this impose on acceleration or control responsiveness? Are the active wheels independently controlled, or do they move in a synchronized manner ? How does the robot maintain balance if one side of the tube has a different texture or friction or if one wheel experiences more resistance than the other ?

2. Why does the thickness-to-diameter ratio of rings (pt) in the kirigami wheel affect the compressive stiffness of the wheel but not fluctuation rate? The kirigami wheel's normal force (F_n) and fluctuation rate (eta_wheel) seems insensitive to changes in the diameter ratio parameter (p_d), as shown in Figure S4A. What structural properties of the layered ring design explain this independence from p_d variations?

3. The paper states that the robot's flow-powering module achieves an impeller speed of up to 9,595 revolutions per minute, with an output power density of 11.7 watts per cubic meter and an efficiency of 33.7%. How were these performance metrics experimentally measured? How might impeller design or housing structure be optimized for higher-load or higher-viscosity environments (e.g., oil pipelines)? Would a variable-geometry impeller help? The paper states that higher viscosity increases impeller drag but also increases robot body drag. Can you elaborate on this competition? At what viscosity does the gain in input torque (via the impeller) become offset by the increase in body drag, preventing upstream motion?

4. The efficiency drops as flow rate or load torque increases beyond certain points. Based on Figure 2F, what physical limitations or design constraints account for this drop in efficiency? A super simplified formula for the energy produced by the impeller would be E = w*N*efficiency*t (w=angular velocity, N=torque, t=time). The graphs in Figure 2F(ii) show that when increasing N, efficiency and angular velocity are reduced monotonically. N increases 500%, efficiency is reduced by a couple percents and angular velocity is reduced 30-40%, so it makes sens that energy density increases. But when N is increased further, energy efficicency, angular velocity and power all have a sudden large drop that does not follow the trend of the curves (quadratic/linear). What physical effect/nonlinearity/limit of the system is causing this penomenon?

5. Fig. 6Aiii shows that for a cylindrical payload with fixed length of 12 mm, the speed of the robot seems to drop abruptly to 0 mm/s when the cylinder diameter reaches 8 mm, while the speed of the robot with a 6 mm diameter payload only dropped by 11.5% compared to the speed without payload. Can you explain why we observe this abrupt stop of the robot motion instead of a smoother speed drop with increasing cylinder diameter (and thus increasing drag)?

6. The impeller used in the wireless flow-powered miniature robot have a "Francis turbine impeller-like shape". One of the biggest issues with Francis turbines is the onset of cavitation near either the trailing or the leading edge of the blades of the impeller. Cavitation is the appearance of gas bubbles inside the fluid, caused by too low pressure due to fluid conditions. The actual results show that the robot was tested up to 1m/s flow rate. As one of the potential applications of this robot would be small scale pipeline inspection, and since flows in pipeline can reach higher speed than 1m/s, should cavitation be considered for the design of the impeller?