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Structural Simulation of Jellyfish Propulsion: Focus on Post-Contraction Dynamics*

Jacob Kaminsky and Jake Kremer

***Abstract*— This goal of this project is to simulate the flexible response of a jellyfish body during the relaxation phase after bell contraction. Using Python, flexible structural models will be developed to mimic the jellyfish's movement, aiming to better understand flexible structures in aquatic environments.**

I. Introduction

Jellyfish are among the most energy-efficient swimmers, largely due to their unique propulsion mechanism. By contracting their bell, they expel water to move forward, followed by a relaxation phase in which the bell passively returns to its original shape. This passive recovery allows jellyfish to maintain forward motion while using minimal energy. Understanding this mechanism through structural modeling could provide insights for bio-mimetic designs in underwater propulsion.

This project focuses specifically on the dynamics of the relaxation phase, where the bell's flexible structure facilitates continuous propulsion. By simulating simplified elements such as rods, rings, and plates, we aim to capture the core principles of jellyfish propulsion mechanics.

II. Background

Past research has primarily focused on the fluid dynamics of jellyfish swimming, while the structural mechanics underlying their movement remain less explored. Jellyfish possess flexible tissues that allow their bell to undergo elastic recovery after each contraction, sustaining propulsion in a low-energy manner. This flexibility is crucial for generating and maintaining movement in the viscous ocean environment.

In this study, we will make use of simplified structural models—a ring to represent the bell's shape, rods for the trailing tentacles, and plates to simulate the surface of the bell. This approach allows us to model how elasticity and passive recovery drive propulsion following bell contraction.

III. Methods

We will use Python to model the structural dynamics of each component:

- Rods will represent flexible, trailing tentacles, responding passively to surrounding fluid forces.
- Rings will simulate the bell's recovery after contraction, providing a restoring force that influences fluid re-entry and propulsion.
- Plates will mimic the bell's surface, expanding and contracting to show how flexible materials impact the overall movement.

*This work was completed under the advisement of Professor M. Khalid Jawed with the University of California, Los Angeles: Department of Mechanical and Aerospace Engineering

A. Equations of Motion

The key forces at play in this phase are the *restoring force* due to elasticity and *drag* from the surrounding water. A simplified equation of motion for the ring structure during relaxation can be given by:

$$m\frac{d^2x}{dt^2} + c\frac{dx}{dt} + kx = F_{\text{drag}} \quad (1)$$

where:

- m is the mass of the ring element,
- c is the damping coefficient of the flexible structure,
- k is the stiffness of the material,
- x is the displacement,
- F_{drag} is the drag force acting opposite to the direction of motion.

The drag force F_{drag} depends on the fluid's viscosity and the velocity of the structure relative to the water:

$$F_{\text{drag}} = -\frac{1}{2}\rho C_d A v^2 \quad (2)$$

where:

- ρ is the fluid density,
- C_d is the drag coefficient (dependent on shape and Reynolds number),
- A is the reference area,
- v is the velocity of the structure.

IV. Discussion

By analyzing the relaxation phase, this model will provide insights into how flexible structures achieve passive energy recovery and propulsion. The balance of elastic forces and drag during this phase is critical in sustaining forward motion with minimal energy expenditure. Varying the stiffness and damping coefficients will allow us to explore the relationship between flexibility and efficient propulsion, potentially informing soft robotic designs that rely on flexible structures for movement in viscous environments.

V. Conclusion

This project aims to simplify and capture the essential mechanics of jellyfish propulsion in the relaxation phase. By examining how flexible structures interact with fluid forces during this phase, we can gain a clearer understanding of the role of structural elasticity in energy-efficient movement.