Summer Research Report—Ming Yang

Subject: fluid-dynamical and optical properties of a species of dinoflagellate

Related research area: differential geometry, fluid dynamics, optics

Research Summary:

The main goal of the research project is to compare two species in the dinoflagellate family, p. lunula and p. fusiformis. Both are marine microorganisms sharing similar biochemistry processes, among which bioluminescence and photosynthesis are of research interest. One main difference is that p.fusiformis has a slender axisymmetric ellipsoidal shape, whereas p.lunula is slightly bent which breaks the rotational symmetry. Since axisymmetric cell body shapes are more commonly seen in nature, we wish to know 1)what is the mechanism of the growth of the cell leading to the breaking of symmetry and 2)what evolutionary benefits does it bring to the cell without rotational symmetry.

For the first problem, I attempted by using differential geometry and considering how it would form the pointy edges first. It is conjectured that the growth speed is related to the local curvature of the surface of the cell and I tried a linear relation. By performing a Taylor expansion and evaluating the dominant terms, I found that the second derivative of the surface function would blow up in finite time provided the local growth speed is negatively correlated with the Gaussian curvatures. The physical meaning beneath is yet to be explored and more research is needed to explain the breaking of symmetry during the growth, but a method involving changing local coordinates is developed and may be helpful for solving the problem.

For the second problem, we first postulated that the breaking of symmetry may help it escape from vortices, which would bring each individual advantage in finding resources in the marine environment. Because the length scale of the microorganism is very small, we studied the Stokes’ equation and the grand resistance matrix for the cell body. We have been searching for past literatures, among which [1] and [2] were the most related. We come up with a model to calculate the grand resistance matrix of p.lunula by using beam-rod model as shown in [3]. However, to simulate the movement in a more realistic way, i.e., to encode the creation and diffusion of vortices, we are required to work in a turbulent flow regime, in which the linearity assumption doesn’t hold and we need to do an immersed boundary problem or two-way coupling system. This understanding of the problem would save time for the further research and we expect interesting fluid dynamical properties to be discovered.

Besides, we come up with the idea that this particular shape may be good for photosynthesis process. Some cell bodies would act as lenses as demonstrated in [4], in which the cell body has a well-understood spherical shape. It is relatively new finding and little research has been conducted in this area. Using ray optics and conclusion in electromagnetism, we found that magnification of the light intensity happens inside the cell body too, and studied the boost effect for relatively simple shape of sphere and infinity long cylinder, which have nice rotational symmetry or translational symmetry allowing for analytic solutions. Ellipsoidal shape and lunular shape are still under calculation, where computer-aided simulation is used. The research in this direction is still ongoing and looks promising.

References

[1] Throp, Ian R. and Lister, John, R. Motion of a non-axisymmetric particle in viscous shear flow. J. Fluid Mech. vol. 872, pp. 532-559

[2] Johnson, Robert E., An improved slender-body theory for Stokes flow. J. Fluid Mech.(1980), vol 99, part 2, pp.411-431

[3] Garcia de la Torre, Jose and Bloomfield, Victor A., Hydrodynamic properties of complex, rigid biological macromolecules: theory and applications. Quarterly Reviews of Biophysics 14, vol 1(1981), pp.81-139

[4]Ueki, Noriko et.al, Eyespot-dependent determination of the phototatctic sign in Chlamydomonas reinhardtii, PNAS, vol.113, no 19, 5299-5304.

Appendix

I did a presentation about the summer project, which briefly summarize the background of this research and several key findings. The slides are attached in the email and can also be view at

https://www.overleaf.com/read/vcpdwkvdkbkp