

Flares and pirouettes: the different moves of spinning bacteria

Bacteria often form together on surfaces in dense communities, known as biofilms. These cause medical and industrial problems because this lifestyle increases their resistance to disease and other stresses, making them difficult to remove. We aim to understand one of the early stages of biofilm formation where individual bacteria initially attach to the surface. We observed bacteria at a surface and saw many types of complex spinning motions. We want to understand the physics causing the different types of motions so we developed a model allowing us to calculate the forces and torques acting on the bacteria.

We looked through a microscope at bacteria in a fluid focusing on motion at a glass surface. We saw different types of spinning motion while part of the bacterium is stuck to the surface. The bacteria spin at various speeds and make different angles with the surface.

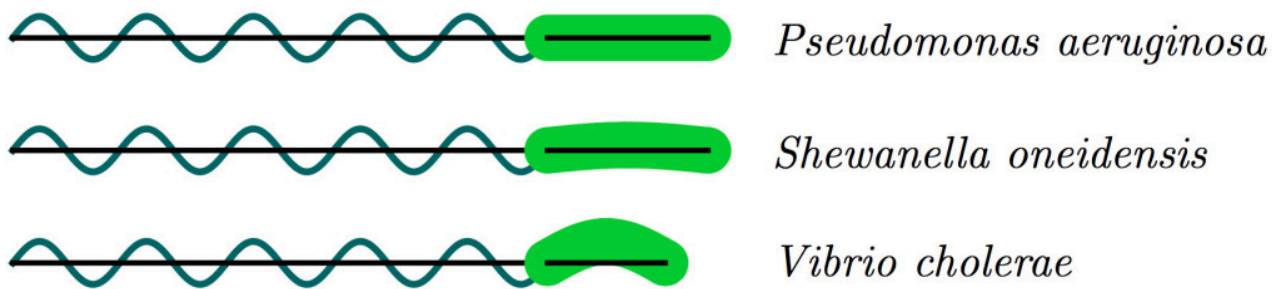


Fig. 1. Shapes of the bacteria species we observe

We use a hydrodynamic model, which calculates the forces and torques between the bacteria, the surface and the surrounding fluid and vary different quantities in the model to see how they affect the spinning behaviour. We observe three different species of bacteria; each bacterium has a rod-like head, one flagellum, which is a thin helical filament, and a motor that rotates the flagellum. The main physical difference between the species is the head shape: *Pseudomonas aeruginosa* has a straight head, *Shewanella oneidensis* has slightly curved head and *Vibrio cholerae* has a very curved head. These shapes are shown in Figure 1.

Which quantities do we vary in our model?

When we see bacteria rotate faster, intuition suggests that the flagellar motor exerts a higher torque. However, torque is not the only factor that affects rotation speed; our model shows that the orientation of a bacterium has a significant effect on the speed due to the resistance from surrounding fluid. There is a flexible joint between the head and the flagella called the flagellar hook; if the hook is very stiff then the head and flagellum will align, if it is not stiff then it is easier for

the head to bend away from the flagellum. In our model we vary the hook stiffness and find that the behaviour depends on the ratio of the hook stiffness and the motor torque.

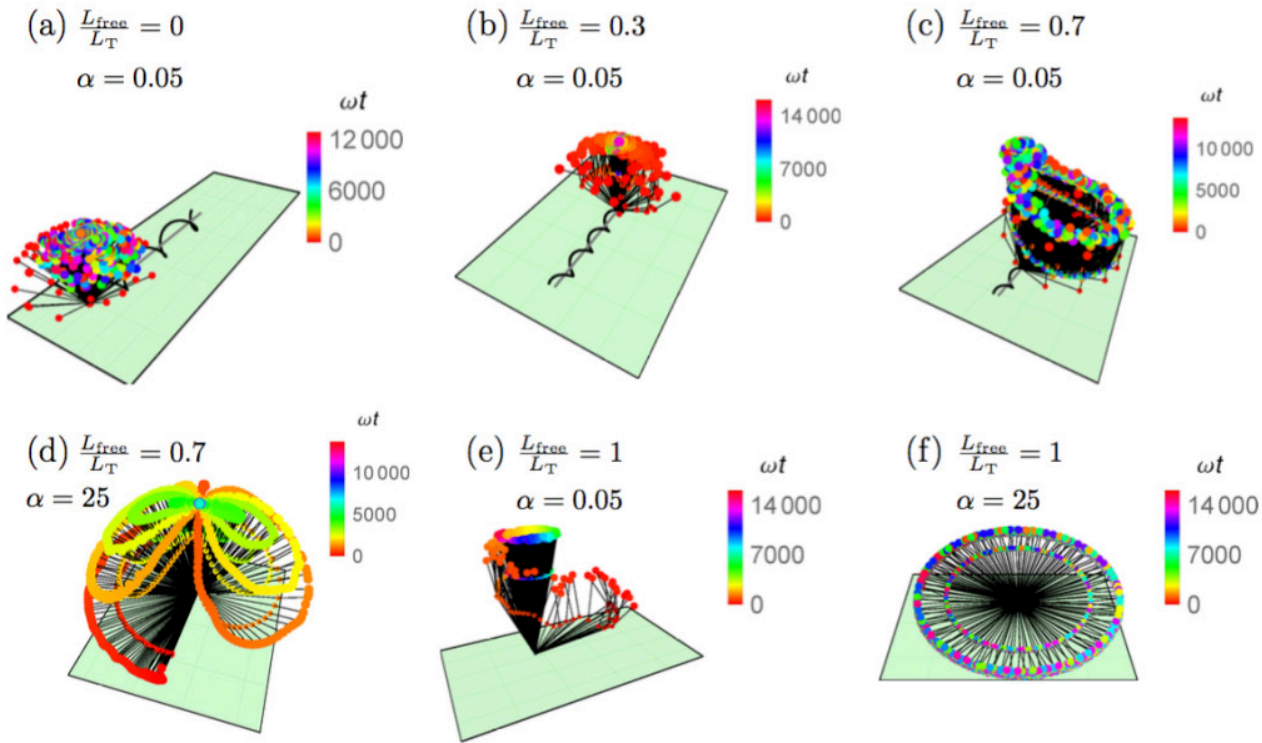


Fig. 2. Diagrams showing some of the types of spinning that the model can produce. The coloured spots trace out the position of each end of the flagellum head with colour representing time. α is the ratio of hook stiffness to motor torque and L_{free}/L_T is the fraction of flagellum that is free.

Part of the flagellum is stuck to the surface and the remainder is free. The ease with which the free part can bend away from the fixed part increases with its length. This length affects the resistance from the fluid: more movement of the flagellum increases resistance, but if the head is further from the surface there is less resistance. Varying the ratio of hook stiffness and motor torque and the length of the free part of the flagellum gives the full range of spinning that we observed experimentally. Figure 2 shows examples of some of the types of motion that our model produces.

All species showed a similar range of spinning behaviour but we observed that the different species detach from the surface at different angles. The model successfully predicts the different detachment angles as a result of the different head shapes.

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Publication

[Species-dependent hydrodynamics of flagellum-tethered bacteria in early biofilm development.](#)

Bennett RR, Lee CK, De Anda J, Nealson KH, Yildiz FH, O'Toole GA, Wong GC, Golestanian R
J R Soc Interface. 2016 Feb