How schools of 'microswimmers' can increase their cargo capacity

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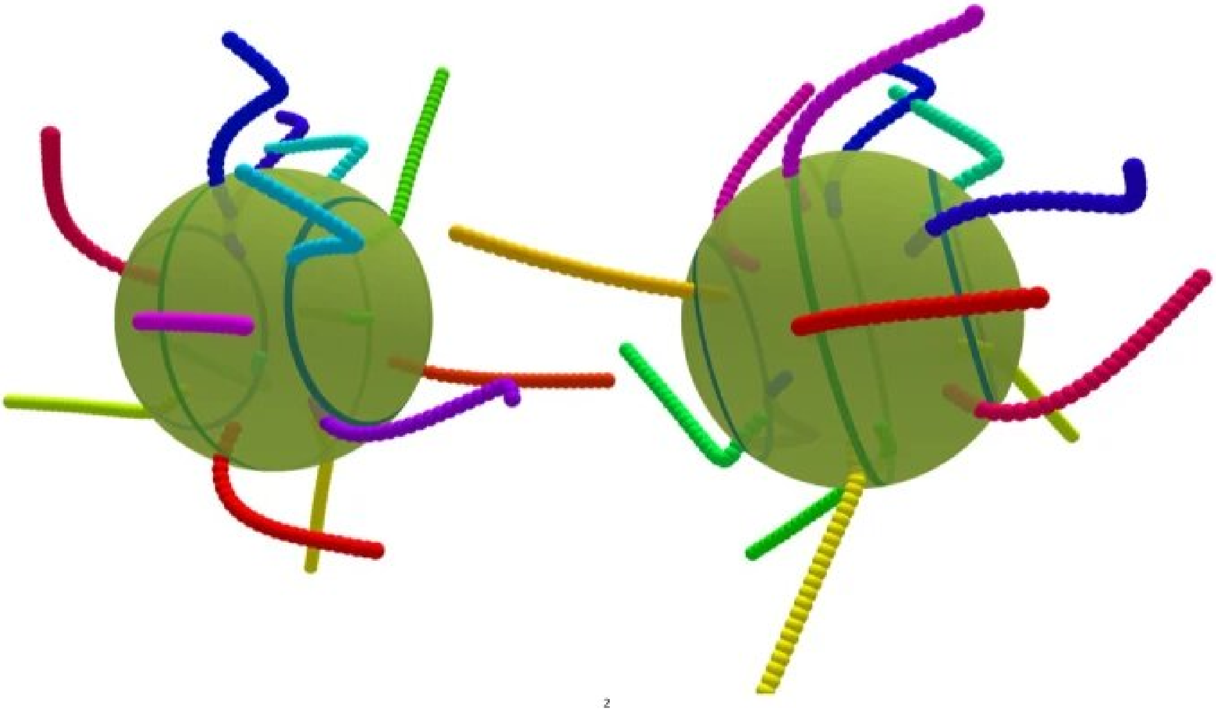

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A new study published in *Physical Review Letters* describes a way to increase the cargo capacity of microscopic, self-propelled droplets known as "microswimmers." Researchers from the University of Pennsylvania and the Max Planck Institute for Dynamics and Self-

Organisation found that when a school of microswimmers move in the same direction inside a narrow channel, they can increase the number of particles they can carry by 10-fold. Their findings have implications for applications ranging from drug delivery systems to materials with active coatings.

Like many scientific endeavors, this one began with a simple observation. While attending a conference dinner at the Georgia Aquarium, physicist Arnold Mathijssen and his colleagues noticed that large schools of swimming fish seemed to be carrying small particles and debris in their wake. This happens because of hydrodynamic entrainment, a process where, as an object moves through liquid, it generates a flow and causes nearby objects to be dragged along with it.

"We were wondering, As the fish in the aquarium are swimming forward, does a particle also get dragged forwards, or is it pushed backwards by their tails?" says Mathijssen. "Our central question was if these guys move things forward or not, and the hypothesis was that, if we can see this happening in the aquarium, maybe this is applicable under a microscope as well."

To answer the question, Max Planck Institute researchers Chenyu Jin, Yibo Chen, and Corinna Maass ran experiments using synthetic microswimmers, self-propelled droplets of oil and surfactant that are a model system for microscopic robots. Using their microswimmers, the researchers were able to measure the strength of the flows generated by an individual swimmer and the amount of material that an individual could carry with them as they traveled through a two-dimensional channel. Then, once the data were collected, Mathijssen and his group developed a theoretical model to help explain their findings.

One particular challenge for developing the model was devising a way to describe the effects of the walls of the microscopic channel because, unlike at the aquarium, this experiment was conducted in a confined space. "That confinement really affects the flows and, as a result, affects the total volume of stuff you can transport. There is quite a bit of literature in terms of modeling active particles, but it's difficult to get it right in complex environments," Mathijssen says.

Using their data and newly-developed model, the researchers found that the transport capacity of an individual microswimmer could be increased by 10-fold when they swam together inside a narrow channel. They also found that the entrainment velocity, or the speed at which particles move forwards, was much larger than initially anticipated.

Compared to a more open system, like the aquarium, having a confined channel seems to enhance the movement of particles, says Mathijssen. "If you are in a three-dimensional world, the energy you inject into your system gets spread out in all directions. Here, where it gets focused into a two dimensional plane, the strength of the flows is larger. It's almost as if you have a wake at the front and the back, so the effect is twice as strong, effectively," he says.

Another surprising finding was how powerful this effect could be even over long distances in a system like this one with a low Reynolds number, a value used by scientists to predict liquid flow patterns. Systems with low Reynolds numbers have smooth, laminar flow (like a waterfall), and those with high values are more turbulent.

"Here, the differences between the low and high Reynolds numbers is that, at low Reynolds numbers, these flows tend to be very long-ranged. Even if you are 10 body lengths away, these flows are still significant. At higher Reynolds numbers, that is not necessarily true because you get a lot of turbulence, and that disturbs this entrainment effect," Mathijssen says.

The researchers think that this could be due to the front and back symmetry that occurs in a closed system. "At low Reynolds numbers, you have a pressure in front of the droplet, and that pressure is pushing the liquid forwards for a large distance," says Mathijssen.

Future experiments will look at how this effect plays out in systems that have higher Reynolds numbers. It's thought that fish rely on a similar phenomenon when they swim close behind each other in large schools, akin to cyclists drafting off one another in a peloton, so the researchers think that a similar effect might be happening in other systems as well.

And because the underlying physics described in this study applies to many others as well, these findings also have implications for a number of other fields, from designing drug-delivery systems, understanding how biofilms transport nutrients, and designing active materials, ones that have unique coatings or properties that imbue them with dynamic features.

"The grander picture in terms of physics is to see how individual active components can work together in order to give rise to a shared functionality, what we call emergent phenomena, at a macroscopic scale," says Mathijssen. "And there, there is no rule book, there are no laws of physics as of yet that describe these systems that are out of equilibrium, so there are fundamental theoretical physics questions that remain to be answered."

More information: Chenyu Jin et al, Collective Entrainment and Confinement Amplify Transport by Schooling Microswimmers, *Physical Review Letters* (2021). DOI: 10.1103/PhysRevLett.127.088006

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