Hydrodynamic functionality of the loric in choanoflagellates

Choanoflagellates are unicellular eukaryotes that are ubiquitous in aquatic habitats. They have a single flagellum that creates a flow toward a collar filter composed of filter strands that extend from the cell. In one common group, the loricate choanoflagellates, the cell is suspended in an elaborate basket-like structure, the loric, the function of which remains unknown. Here, we use Computational Fluid Dynamics to explore the possible hydrodynamic function of the loric. We use the choanoflagellate Diaphanoea grandis as a model organism. It has been hypothesized that the function of the loric is to prevent refiltration (flow recirculation) and to increase the drag and, hence, increase the feeding rate and reduce the swimming speed. We find no support for these hypotheses. On the contrary, motile prey are encountered at a much lower rate by the loricate organism. The presence of the loric does not affect the average swimming speed, but it suppresses the lateral motion and rotation of the cell. Without the loric, the cell jiggles from side to side while swimming. The unsteady flow generated by the beating flagellum causes reversed flow through the collar filter that may wash away captured prey while it is being transported to the cell body for engulfment. The loric substantially decreases such flow, hence it potentially increases the capture efficiency. This may be the main adaptive value of the loric.
Hydrodynamic functionality of the lorica in choanoflagellates

Choanoflagellates are unicellular microswimmers that are ubiquitous in aquatic habitats. They have a single flagellum that creates a flow toward the collar, the filtration apparatus composed of closely spaced filter strands. Loricate choanoflagellates have evolved a basket-like “skeleton” around the cell, the lorica, the function of which remains unknown.

Here, we use Computational Fluid Dynamics (CFD) to explore the possible hydrodynamic function of the lorica by studying the choanoflagellate Diaphanoeca grandis, with and without its lorica. We study the flow rate, the flow recirculation, and the resulting clearance rate for the capture of motile and non-motile prey by the freely swimming choanoflagellate. We find no support for several previous hypotheses regarding the effects of the lorica. Rather, our simulations suggest that the main function of the lorica is to enhance the capture efficiency, but this happens at the cost of lower encounter rate with motile prey.

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Hydrodynamics of small marine organisms: A mechanistic exploration of traits and trade-offs for flagellates and filter feeders

Although typically not visible to the naked eye, planktonic organisms play key roles for the functioning of the aquatic ecosystem. They display a huge morphological and functional diversity ranging from microscopic bacteria to meter-sized gelatinous organisms. Due to their intimate interaction with the water as habitat and medium, flows are essential to the survival strategies of plankton. Many, even unicellular, species are motile and create various kinds of flows that accompany swimming and can be used for prey and nutrient collection. On the other hand, the flow disturbances due to prey organisms can also be used by predators for remote detection via flow-sensing. In this study we use mechanistic models to explore and quantify the traits and trade-offs that relate to the swimming, feeding, and predator avoidance in small marine organisms.

Unicellular flagellates create flows with whip-like appendages that in different species can have various numbers, lengths, and beat patterns. We use an analytical hydrodynamics model to distinguish those characteristics. We represent the cell body as a solid sphere and the action of each flagellum by a point force on the water that creates a flow and propels the organism. The different swimming modes are quantified by the number, magnitude, position, and direction of the point forces in the model, which lead to specific flow patterns and kinematics. We use the model to represent two biflagellated haptophyte species that both have a left-right symmetric flagellar arrangement, but different lengths and beat patterns. The time-resolved near-cell flows that are measured with micro particle image velocimetry can be well represented by the analytical model and allow us to assign characteristic average force positions to the two species. By calculating swimming speed, size of the disturbance zone, and advective prey encounter rates for different force positions, we find that equatorial arrangements are favoured for fast and stealthy swimming, while puller swimmers with front arrangements exhibit increased prey encounter rates. We present further possibilities of the model to evaluate the swimming speed due to different forces during a periodic swimming stroke and to calculate characteristics of the helical trajectory for asymmetric swimmers.

A second group of organisms that we investigate are filter feeders that use fibrous filter structures to collect and sieve prey from the dilute suspension that ocean water represents. We closely investigate microbial filter feeding on the example of choanoflagellates, which are unicellular organisms that use a single flagellum to drive a feeding flow through a collar filter. The volume flow rates of individuals measured with micro particle tracking velocimetry can be well represented by the analytical model and allow us to assign characteristic average force positions to the two species. We use mechanistic models to explore and quantify the traits and trade-offs that relate to the swimming, feeding, and predator avoidance in small marine organisms.

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An analytical model of flagellate hydrodynamics
Flagellates are unicellular microswimmers that propel themselves using one or several beating flagella. We consider a hydrodynamic model of flagellates and explore the effect of flagellar arrangement and beat pattern on swimming kinematics and near-cell flow. The model is based on the analytical solution by Oseen for the low Reynolds number flow due to a point force outside a no-slip sphere. The no-slip sphere represents the cell and the point force a single flagellum. By superposition we are able to model a freely swimming flagellate with several flagella. For biflagellates with left–right symmetric flagellar arrangements we determine the swimming velocity, and we show that transversal forces due to the periodic movements of the flagella can promote swimming. For a model flagellate with both a longitudinal and a transversal flagellum we determine radius and pitch of the helical swimming trajectory. We find that the longitudinal flagellum is responsible for the average translational motion whereas the transversal flagellum governs the rotational motion. Finally, we show that the transversal flagellum can lead to strong feeding currents to localized capture sites on the cell surface.
Computational Fluid Dynamics of Choanoflagellate Filter-Feeding
Choanoflagellates are unicellular aquatic organisms with a single flagellum that drives a feeding current through a funnel-shaped collar filter on which bacteria-sized prey are caught. Using computational fluid dynamics (CFD) we model the beating flagellum and the complex filter flow of the choanoflagellate Diaphanoeca grandis. Our CFD simulations based on the current understanding of the morphology underestimate the experimentally observed clearance rate by more than an order of magnitude: The beating flagellum is simply unable to draw enough water through the fine filter. Our observations motivate us to suggest a radically different filtration mechanism that requires a flagellar vane (sheet), and addition of a wide vane in our CFD model allows us to correctly predict the observed clearance rate.

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Computational Fluid Dynamics of Choanoflagellate Filter-Feeding
Choanoflagellates are unicellular aquatic organisms with a single flagellum that drives a feeding current through a funnel-shaped collar filter on which bacteria-sized prey are caught. Using computational fluid dynamics (CFD) we model the beating flagellum and the complex filter flow of the choanoflagellate Diaphanoeca grandis. Our CFD simulations based on the current understanding of the morphology underestimate the experimentally observed clearance rate by more than an order of magnitude: The beating flagellum is simply unable to draw enough water through the fine filter. Our observations motivate us to suggest a radically different filtration mechanism that requires a flagellar vane (sheet), and addition of a wide vane in our CFD model allows us to correctly predict the observed clearance rate.

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Hydrodynamics of microbial filter feeding

Microbial filter feeders are an important group of grazers, significant to the microbial loop, aquatic food webs, and biogeochemical cycling. Our understanding of microbial filter feeding is poor, and, importantly, it is unknown what force microbial filter feeders must generate to process adequate amounts of water. Also, the trade-off in the filter spacing remains unexplored, despite its simple formulation: A filter too coarse will allow suitably sized prey to pass unintercepted, whereas a filter too fine will cause strong flow resistance. We quantify the feeding flow of the filter-feeding choanoflagellate Diaphanoeca grandis using particle tracking, and demonstrate that the current understanding of microbial filter feeding is inconsistent with computational fluid dynamics (CFD) and analytical estimates. Both approaches underestimate observed filtration rates by more than an order of magnitude; the beating flagellum is simply unable to draw enough water through the fine filter. We find similar discrepancies for other choanoflagellate species, highlighting an apparent paradox. Our observations motivate us to suggest a radically different filtration mechanism that requires a flagellar vane (sheet), something notoriously difficult to visualize but sporadically observed in the related choanocytes (sponges). A CFD model with a flagellar vane correctly predicts the filtration rate of D. grandis, and using a simple model we can account for the filtration rates of other microbial filter feeders. We finally predict how optimum filter mesh size increases with cell size in microbial filter feeders, a prediction that accords very well with observations. We expect our results to be of significance for small-scale biophysics and trait-based ecological modeling.

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Scopus rating (2012): CiteScore 9.49 SJR 6.868 SNIP 2.697
Swimming and feeding of mixotrophic biflagellates

Many unicellular flagellates are mixotrophic and access resources through both photosynthesis and prey capture. Their fitness depends on those processes as well as on swimming and predator avoidance. How does the flagellar arrangement and beat pattern of the flagellate affect swimming speed, predation risk due to flow-sensing predators, and prey capture? Here, we describe measured flows around two species of mixotrophic, biflagellated haptophytes with qualitatively different flagellar arrangements and beat patterns. We model the near cell flows using two symmetrically arranged point forces with variable position next to a no-slip sphere. Utilizing the observations and the model we find that puller force arrangements favour feeding, whereas equatorial force arrangements favour fast and quiet swimming. We determine the capture rates of both passive and motile prey, and we show that the flow facilitates transport of captured prey along the haptonema structure. We argue that prey capture alone cannot fulfill the energy needs of the observed species, and that the mixotrophic life strategy is essential for survival.

General information
Diffusion and bulk flow in phloem loading: a theoretical analysis of the polymer trap mechanism for sugar transport in plants

Plants create sugar in the mesophyll cells of their leaves by photosynthesis. This sugar, mostly sucrose, has to be loaded via the bundle sheath into the phloem vascular system (the sieve elements), where it is distributed to growing parts of the plant. We analyze the feasibility of a particular loading mechanism, active symplasmic loading, also called the polymer trap mechanism, where sucrose is transformed into heavier sugars, such as raffinose and stachyose, in the intermediary-type companion cells bordering the sieve elements in the minor veins of the phloem. Keeping the heavier sugars from diffusing back requires that the plasmodesmata connecting the bundle sheath with the intermediary cell act as extremely precise filters, which are able to distinguish between molecules that differ by less than 20% in size. In our modeling, we take into account the coupled water and sugar movement across the relevant interfaces, without explicitly considering the chemical reactions transforming the sucrose into the heavier sugars. Based on the available data for plasmodesmata geometry, sugar concentrations, and flux rates, we conclude that this mechanism can in principle function, but that it requires pores of molecular sizes. Comparing with the somewhat uncertain experimental values for sugar export rates, we expect the pores to be only 5%-10% larger than the hydraulic radius of the sucrose molecules. We find that the water flow through the plasmodesmata, which has not been quantified before, contributes only 10%-20% to the sucrose flux into the intermediary cells, while the main part is transported by diffusion. On the other hand, the subsequent sugar translocation into the sieve elements would very likely be carried predominantly by bulk water flow through the plasmodesmata. Thus, in contrast to apoplasmic loaders, all the necessary water for phloem translocation would be supplied in this way with no need for additional water uptake across the plasma membranes of the phloem.

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Energy harvesting through gas dynamics in the free molecular flow regime between structured surfaces at different temperatures

For a gas confined between surfaces held at different temperatures the velocity distribution shows a significant deviation from the Maxwell distribution when the mean free path of the molecules is comparable to or larger than the channel dimensions. If one of the surfaces is suitably structured, this nonequilibrium distribution can be exploited for momentum transfer in a tangential direction between the two surfaces. This opens up the possibility to extract work from the system which operates as a heat engine. Since both surfaces are held at constant temperatures, the mode of momentum transfer is different from the thermal creep flow that has gained more attention so far. This situation is studied in the limit of free-molecular flow for the case that an unstructured surface is allowed to move tangentially with respect to a structured surface. Parameter studies are conducted, and configurations with maximum thermodynamic efficiency are identified. Overall, it is shown that significant efficiencies can be obtained by tangential momentum transfer between structured surfaces.
Hydrodynamics of small Marine Organisms
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Lauga, E., Examiner
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15/12/2014 → 11/04/2018
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Project: PhD

Activities:
Complex Motion in Fluids Summer School
Period: 24 Sep 2017 → 29 Sep 2017
Seyed Saeed Asadzadeh (Participant)
Jens Honore Walther (Participant)
Lasse Tor Nielsen (Participant)
Julia Dölger (Participant)
Thomas Kiørboe (Participant)
Anders Peter Andersen (Participant)
Department of Mechanical Engineering
Fluid Mechanics, Coastal and Maritime Engineering
National Institute of Aquatic Resources
Centre for Ocean Life
Department of Physics
Biophysics and Fluids

Description
The school will consist of 16 lectures in total, given by 8 speakers (90'+60' each), contributed talks, poster sessions and other activities.
Degree of recognition: International
Documents:
Asadzadeh

Related event
Complex Motion in Fluids Summer School
24/09/2017 → 30/09/2017
Cambridge, United Kingdom
Activity: Attending an event › Participating in or organising workshops, courses, seminars etc.