Computational Fluid Dynamics of Choanoflagellate Filter-Feeding

Asadzadeh, Seyed Saeed; Walther, Jens Honore; Nielsen, Lasse Tor; Kiørboe, Thomas; Dölger, Julia; Andersen, Anders Peter

Publication date: 2017

Document Version
Publisher's PDF, also known as Version of record

Link back to DTU Orbit

Citation (APA):

General rights
Copyright and moral rights for the publications made accessible in the public portal are retained by the authors and/or other copyright owners and it is a condition of accessing publications that users recognise and abide by the legal requirements associated with these rights.

- Users may download and print one copy of any publication from the public portal for the purpose of private study or research.
- You may not further distribute the material or use it for any profit-making activity or commercial gain
- You may freely distribute the URL identifying the publication in the public portal

If you believe that this document breaches copyright please contact us providing details, and we will remove access to the work immediately and investigate your claim.
Computational Fluid Dynamics of Choanoflagellate Filter-Feeding

S.S.Asadzadeh1,∗, J.H.Walther1,∗, L.T.Nielsen1, T.Kiørboe1, J.Dölger4, A.Andersen1

1Department of Mechanical Engineering, Technical University of Denmark.
2Computational Science and Engineering Laboratory, ETH, Zürich, Switzerland
3National Institute of Aquatic Resources and Centre for Ocean Life
4Department of Physics and Centre for Ocean Life, Technical University of Denmark
∗E-mail: sesasa@mek.dtu.dk

Websites: www.fvm.mek.dtu.dk; www.oceanlifecentre.dk

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.

Morphology of Choanoflagellate *Diaphanoeca grandis*

![Morphology of *Diaphanoeca grandis*.](image)

Morphology of *Diaphanoeca grandis*. (A) Microscopic image of freely swimming choanoflagellate. (B) Model morphology with cell (orange), collar filter (green surface and black lines), flagellum (blue), and lorica (red) (C) By beating their flagellum, the choanoflagellates create a flow of water across the collar filter, and this collar filters out prey.

Governing equations and numerical method

Governing equations are the continuity and Navier-Stokes equations:

\[ \nabla \cdot u = 0 \]

(1)

\[ \Re(\frac{1}{\Str} \frac{\partial u}{\partial t} + (u \cdot \nabla)u) = -\nabla p + \nabla \cdot \tau \]

(2)

where \( u \) and \( p \) are dimensionless velocity and pressure, respectively, and \( \Re = \frac{UL}{\nu} \approx 0.0007 \) is the Reynolds number, and \( \Str = \frac{fL}{U} \approx 0.77 \) is Strouhal number, where \( U, L \) and \( f \) are the characteristic velocity, length and frequency.

The computational domain is discretized with 4.8 million computational cells. (A) The mesh is chosen very fine around the flagellum and in between the microvilli to resolve the flow structures, whereas a coarse mesh is sufficient to resolve the flow in the far field. (B and C) Details of the mesh between the microvilli seen from the side and in the z direction. (We apply the commercial CFD program STAR-CCM+ version 12.02.010-R8).

Observed versus modelled feeding flow

![Observed feeding flow and velocity field from CFD model.](image)

Observed feeding flow and velocity field from CFD model based on the standard description of morphology and flagellum. (A) Representative particle tracks. (B) Average velocity field based on particle tracking. (C) The CFD velocity field in the xz plane is time averaged over the flagellar beat cycle, and the velocity vectors inside filter and chimney are omitted for clarity. The CFD model based on the standard description of morphology and flagellum predicts a feeding flow that is more than an order of magnitude weaker than the experimentally observed flow, and it fails for the observed clearance rate.

CFD model with flagellar vane

![CFD model with flagellar vane.](image)

A flagellar vane is notoriously difficult to visualize, but sporadically observed in some species of the choanoflagellates. (A) the choanoflagellate *Monosiga brevicollis* (scale bar 2\( \mu m \)), and (F,G) the choanocyte of the sponge *Spongilla lacustris*. The vane spans the width of the collar. (scale bar 1\( \mu m \)) [1].

![Representative particle tracks.](image)

(A) The model morphology shows organism with 5\( \mu m \) wide flagellar vane (blue). (B) Observed average velocity field. (C) The CFD velocity field in the xz plane is time averaged over the flagellar beat cycle, and the velocity vectors inside filter and chimney are omitted for clarity. The CFD model with a flagellar vane predicts a feeding flow and a clearance rate in good agreement with the experimental observation.

References


Acknowledgements

We gratefully acknowledge funding from the Villum Foundation.