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► **To cite this version:**

Astrid Decoene, Sébastien Martin, Fabien Vergnet. A continuum active structure model for the interaction of cilia with a viscous fluid. Enumath 2023 - European Conference on Numerical Mathematics and Advanced Applications, Sep 2023, Lisbon, Portugal. 10.1002/zamm.202100534 . hal-04396601

HAL Id: hal-04396601

<https://hal.science/hal-04396601v1>

Submitted on 16 Jan 2024

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A continuum active structure model for the interaction of cilia with a viscous fluid

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Abstract

Cilia and flagella are motile elongated structures, involved in swimming and/or transport mechanisms that arise in many living organisms. Flagella are used by micro-swimmers such as sperm-cells or bacteria for motility purpose at low Reynolds number, while cilia are involved in the transport of proteins, nutrients or dust inside bigger organisms. At the origin of all these mechanisms are two essential ingredients: the capacity for cilia and flagella to modify their shapes by generating internal stresses and the strong reciprocal interaction with the surrounding fluid.

Both aspects have been studied in several works, with very different strategies. Cilia can either be modeled as 1D elastic structures with self-oscillatory [1] and sliding regulation mechanisms [2] or as 3D structures with a discrete representation of their internal biological components [3]. In the first case, the coupling with the surrounding 3D fluid is often taken into account (numerically) with the slender body theory [4]. In the second case, the fluid-structure interaction is well resolved but the (discrete) model for cilia is not suitable for the mathematical analysis and introduces many parameters that may not be accessible in experiments.

Unlike all previous works on cilia and flagella, we propose a model that fits in the framework of continuum mechanics. In the context of 2D or 3D elasticity, the model is based upon the definition of a suitable Piola-Kirchoff tensor mimicking the action of the internal components that induce the motility of the structure. Moreover, the framework of continuum mechanics enables to fully consider the strong interaction with the surrounding fluid. During this presentation, we will show that the present model is suitable for both the mathematical study and the numerical simulation of fluid-structure interaction problems involving active structures and low Reynolds number flows. We shall also discuss the question of the identification of the internal activity.

Keywords: Active structures, Fluid-structure interaction problems, Mucociliary transport, Optimal control

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