The swimming problem consists in controlling the rigid displacement of a (deformable) object placed in a fluid. In order to move the object, one acts on controls which are the (non-rigid) deformations of the object. The equations connecting the rigid deformation to the non-rigid deformation are obtained by a coupling between the partial differential equations modeling the motion of the fluid (the Navier-Stokes equations) and the fundamental principle of the dynamics (Newton's laws), describing the rigid motion of the swimmer. These two systems are coupled by the continuity of the velocities at the swimmer's boundary. The corresponding system is considered as a control system where the input of the system is the deformation imposed on the swimmer and the output is the position and orientation of the swimmer. Several theoretical studies of this problem have been carried out in the limiting cases of low Reynolds numbers or high Reynolds number. In these cases, one can approach the Navier-Stokes equations by the Stokes equations or by a Poisson problem (potential fluid), and in some cases one can obtain explicit formulas of the solution of the system.

A first line of research will consist of extending and improving existing controllability results. It has been shown that generically only four independent deformations are enough to control an isolated swimmer surrounded by a fluid. A first objective of the thesis would be to reduce the number of controls. This can be done by computing high order Lie brackets. In a second time, it will be possible to look at the case where the swimmer is confined in a bounded cavity. It was noted in previous works that the boundary of this cavity could play a role in the swimming mechanism. The last extension could be to generalize the controllability results on the low Reynolds swimmers to the case of high Reynolds numbers.

A second line of research will be to understand the structure of the optimal swimming. Given the physical nature of the system considered, it is natural to impose constraints on the swimmer's deformation and speed of deformation. Typically, we will assume that the control is bounded and that the deformation parameters belong to a compact set. These constraints induce the existence of a minimum control time to send the swimmer to a prescribed target. The object is to better understand this minimum time function and the structure of time optimal controls (periodicity, regularity, etc.).

Finally the last axis of the thesis will focus on the validation of the theoretical results by numerical simulations. This will allow us in particular to support our intuition in many cases where we are not able to rigorously demonstrate some results. This requires first to develop a rapid numerical method for solving the direct problem where the swimming mechanism is prescribed (without specifying a potential fluid), and in some cases one can obtain explicit formulas of the solution of the system.
position objective). In the limit case of low Reynolds numbers, it is possible to consider boundary integral methods, whose interests are the computational speed and the accuracy of the swimmer’s geometry. However, this method is difficult to generalize in the other cases. Once the direct problem has been implemented, it will be necessary to focus on the minimization of a cost (optimal control problem). Solving such problems is usually difficult to implement. A strategy can be the use of homotopy methods in order to take advantage of our good understanding of the limit case of low Reynolds numbers.

**Compétences**

**Required qualifications**

MSc in mathematics

**Language**

French or English.

**Avantages sociaux**

- Subsidised catering service
- Partially-reimbursed public transport
- Social security
- Paid leave
- French courses

**Rémunération**


Monthly salary after taxes: around 1596,05€ for 1st and 2nd year. 1678,99€ for 3rd year. (medical insurance included).

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