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## A hydrodynamic toy model for fish locomotion

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## 0. State of the art

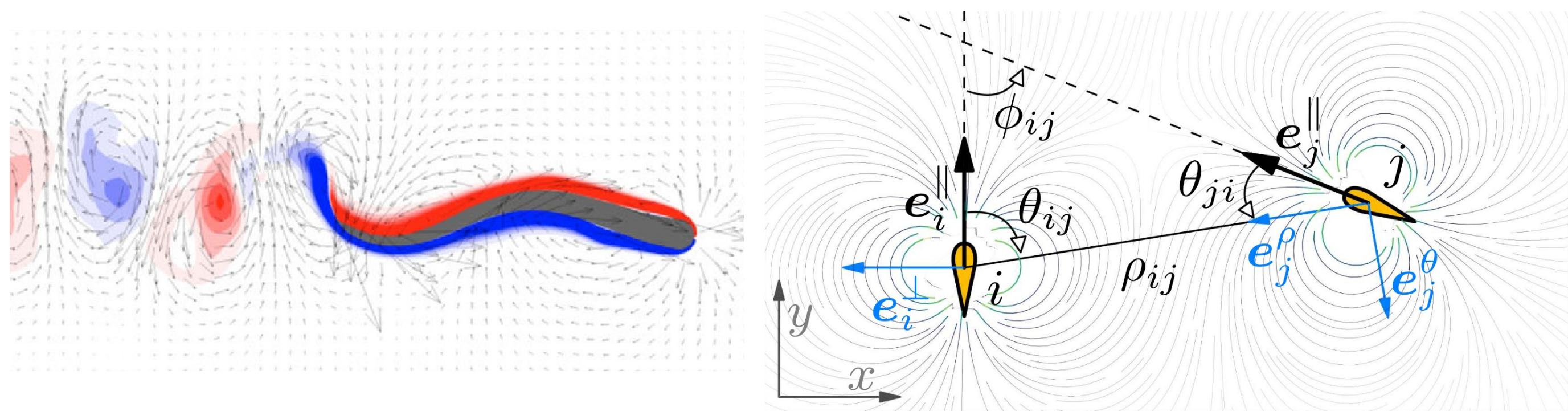
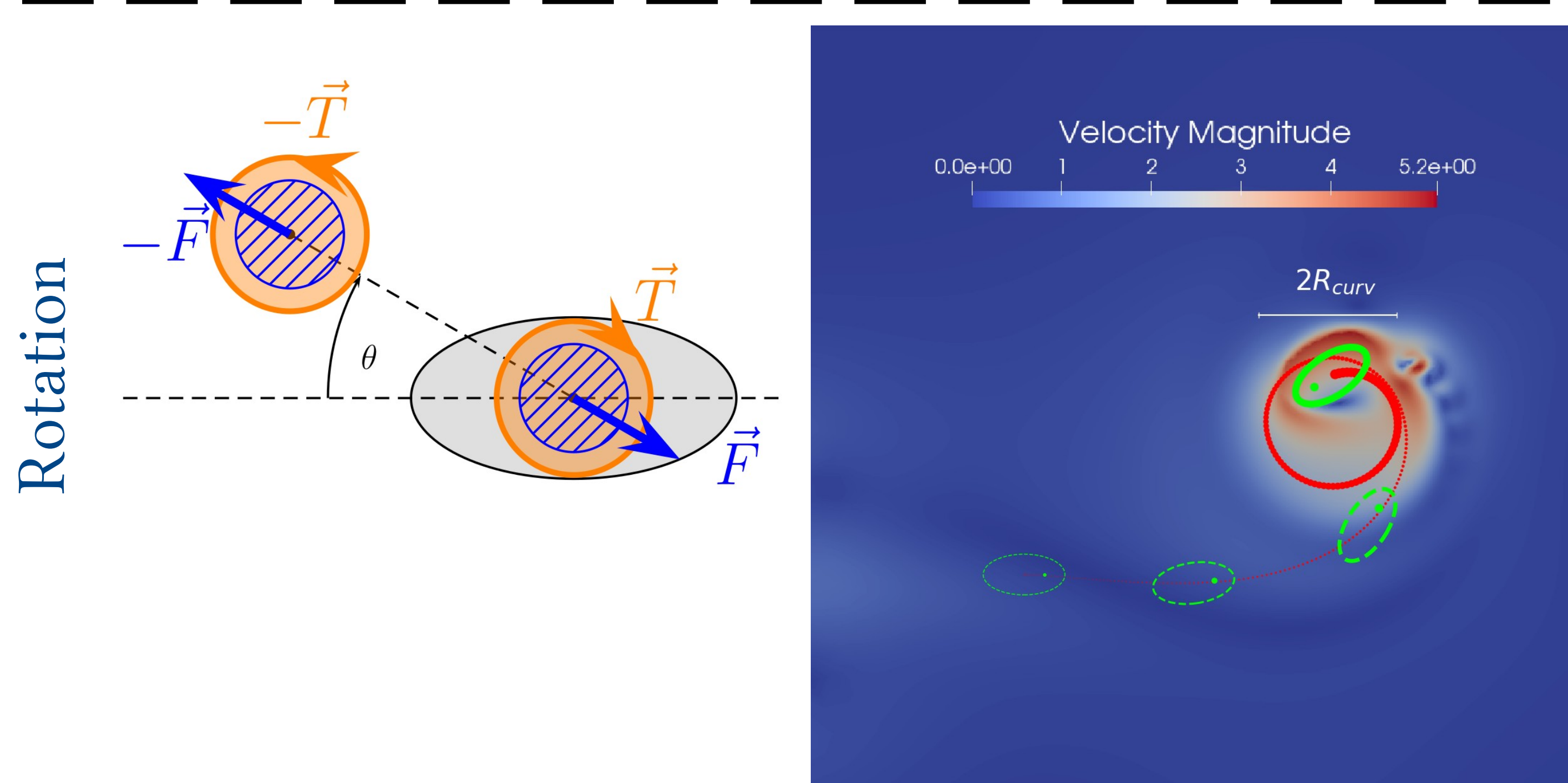
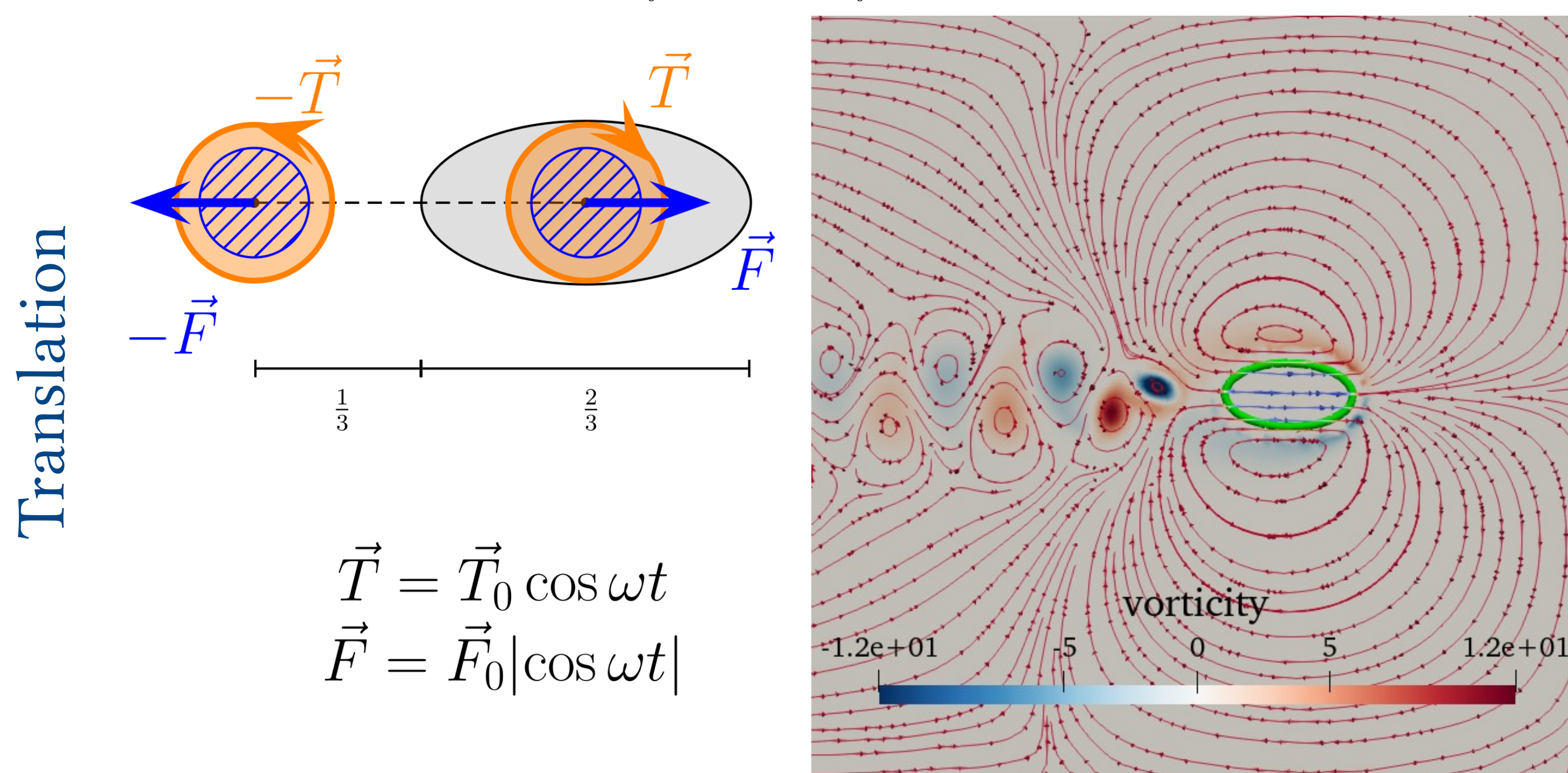


Figure: Left. Numerical velocity field of a swimming fish taken from [Kern06]. Colors correspond to the vorticity field. Right. Illustration of the dipole field and the interaction used in [Fillela18] to study the hydrodynamic interaction in collective fish behavior .

## I. The toy model definition

- The fish is defined a rigid body with a ellipsoidal shape
- The rigid body is defined by a penalization in viscosity:  $\frac{\mu_{Rigid\ Body}}{\mu_{Fluide}} = 10^6$
- The tail flapping is described by local forces directly applied in the Navier-Stokes Eq.
 
$$\rho \left( \frac{\partial \vec{v}}{\partial t} + (\vec{v} \cdot \nabla) \vec{v} \right) = -\nabla p + \nabla \cdot \left( \mu \frac{\nabla \vec{v} + \nabla \vec{v}^T}{2} \right) + \sum_i \vec{F}_{Torque}^i + \sum_i \vec{F}_{Dipole}^i$$
- Solved using FEEL++ [1], a finite element C++ library.
- Control parameters are: the torque  $T_0$ , the force  $F_0$  and the pulsation  $\omega$ .



## A hydrodynamic toy model for fish locomotion



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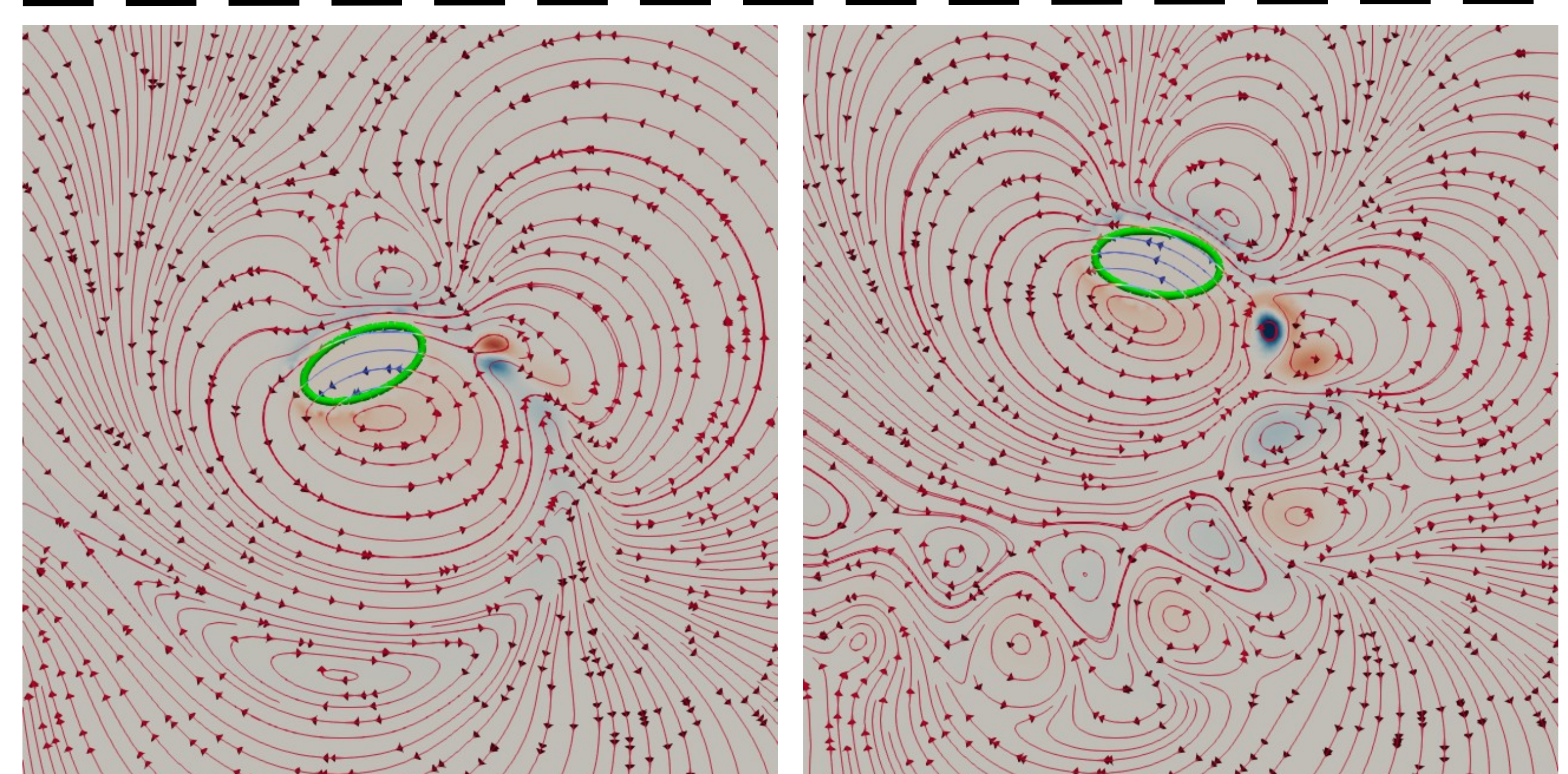
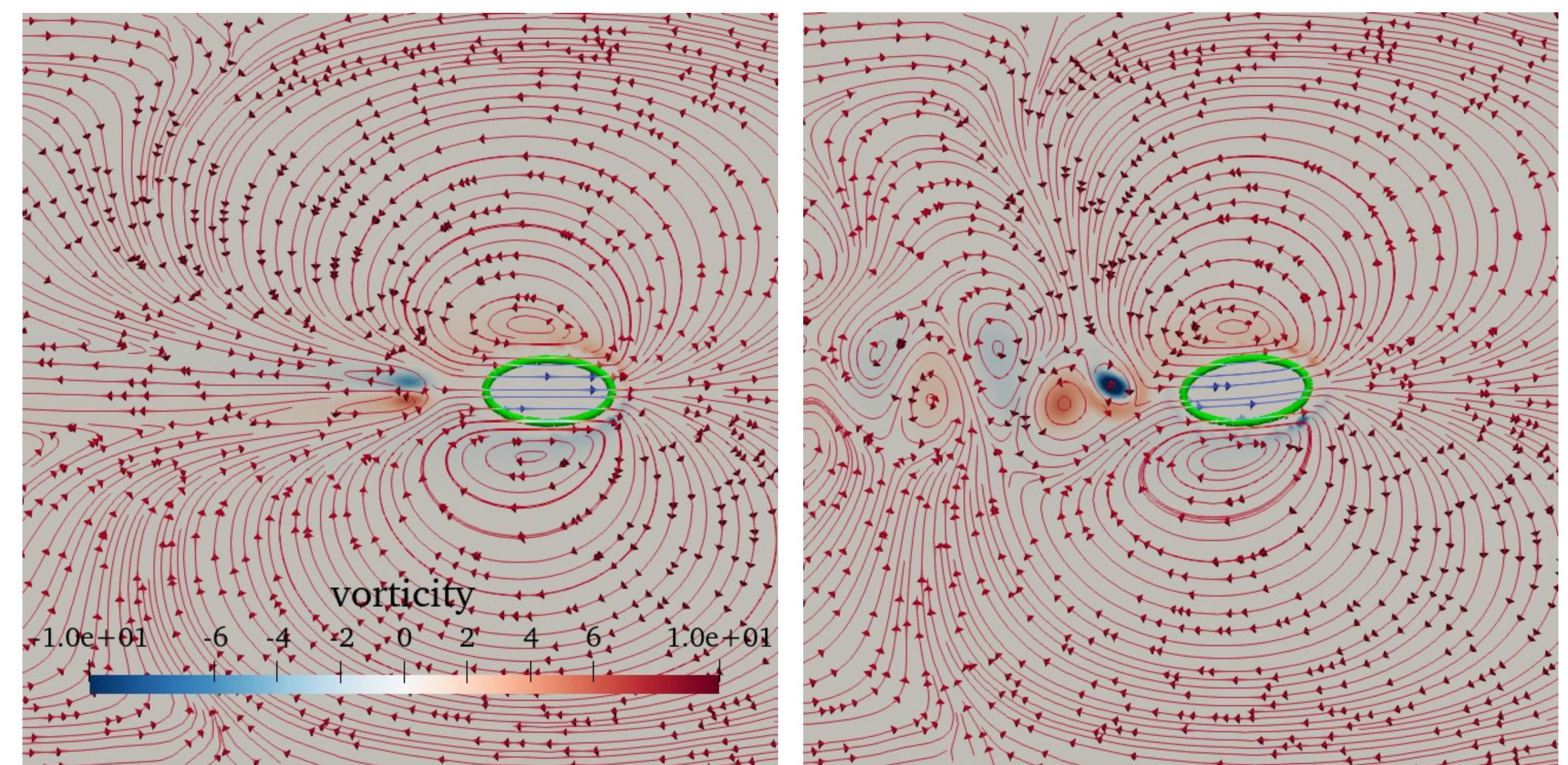
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## II. Velocity field

Re=60,  $F_0=150$

No Torque  $T_0=0$

With Torque  $T_0=450$



## III. Tuning the behavior

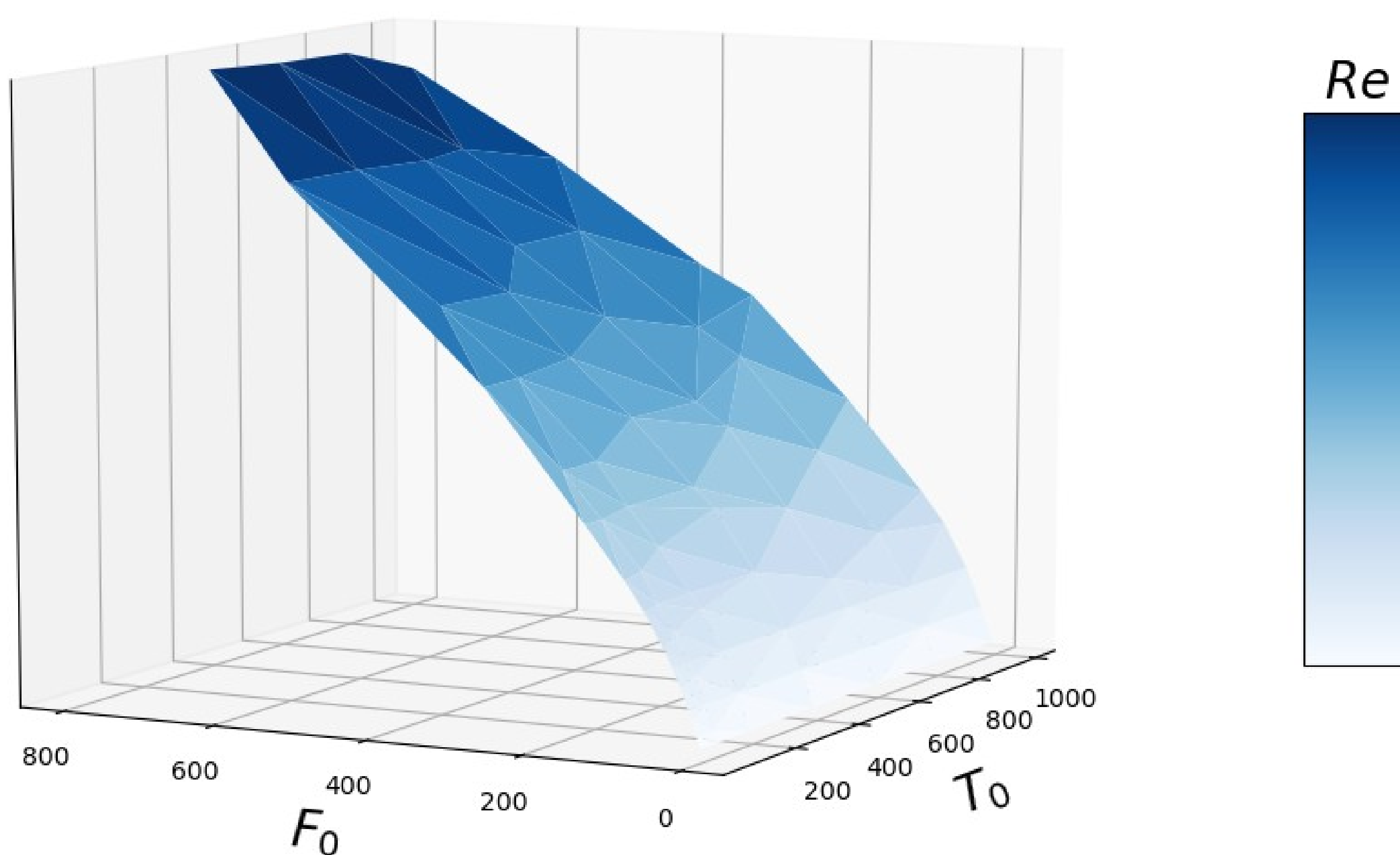


Figure: Re number as a function of the dipole amplitude and the torque amplitude. The virtual tail is in the neutral position ( $\theta=0$ )

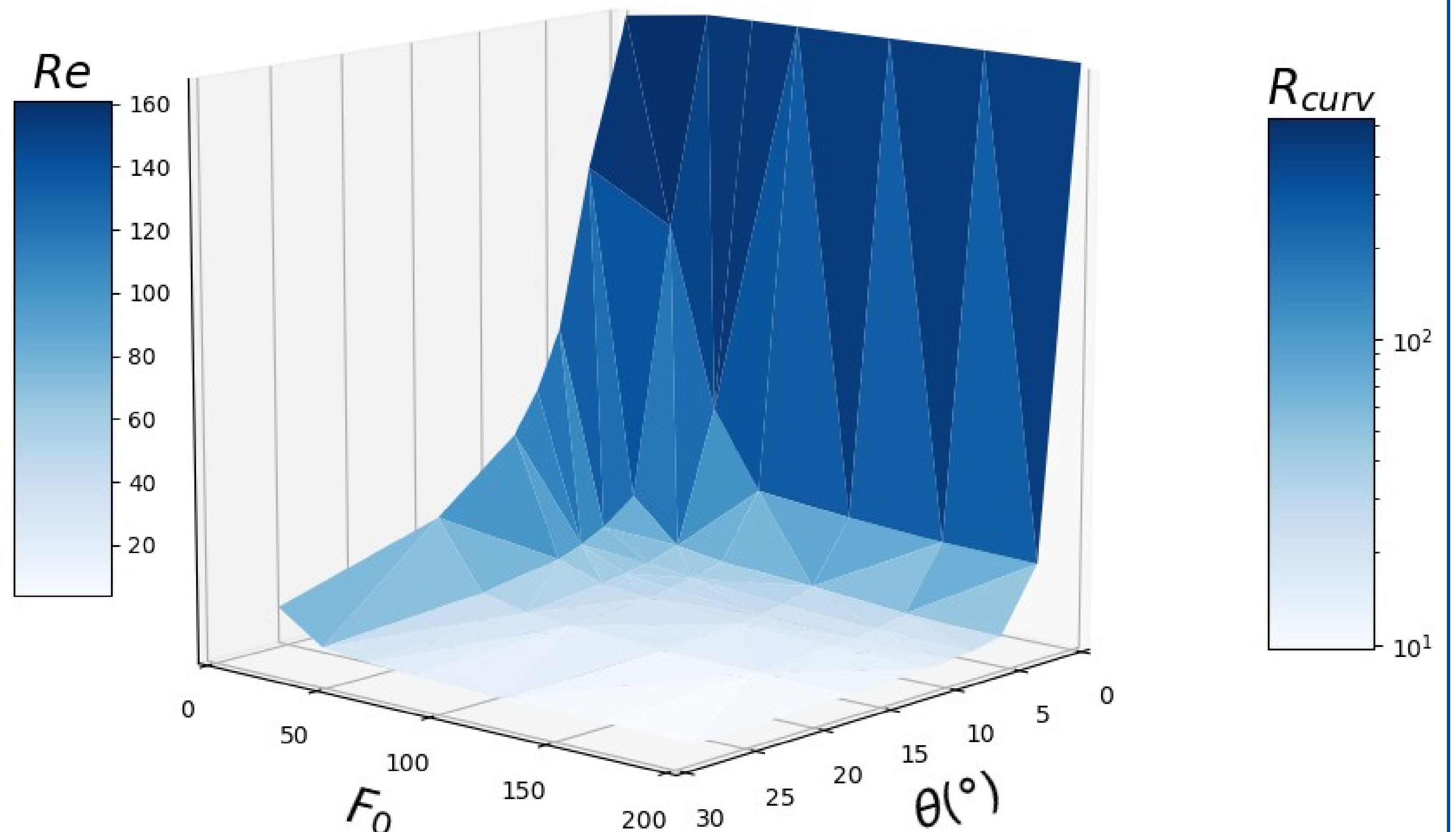


Figure: Radius of curvature as a function of the dipole amplitude and the shift of the virtual tail position. The torque amplitude is fixed  $T_0=450$ .

[Kern06] Kern S., Koumoutsakos P., Simulations of optimized anguilliform swimming, J. Experimental Biology, 209, 4841-4857, 2006

[Fillela18] Audrey Fillella, Francois Nadal, Clément Sire, Eva Kanso and Christophe Eloy. Model of collective fish behavior with hydrodynamic interactions. Physical Review Letters, May 11, 2018

[1] <https://github.com/feelpp/feelpp>

## Conclusions

- We manage to reproduce and control the amplitude of the vortex wake behind a fish with a minimal model
- Next steps are:
  - Do the link between  $\omega$  and  $T_0$ ,  $F_0$  to convert social parameters into force parameters
  - Check the scaling of the Re as a function of  $\omega$