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The application of Multi-body Dynamics Theory on fish locomotion

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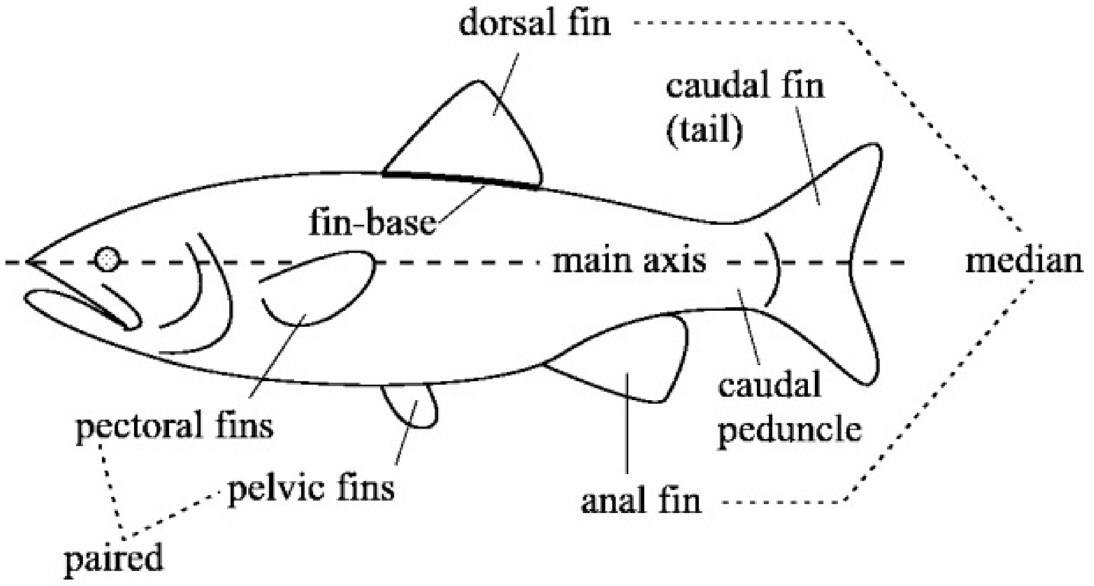
Background

1. Excellent ability of propulsion and manoeuvring of fish.
2. Seeking the principles of fish swimming
3. Deep study of the fish locomotion in water
4. Previous studies: only fish body or fins
5. Current project: flexible body motion, meanwhile coupled with the motions of several fins

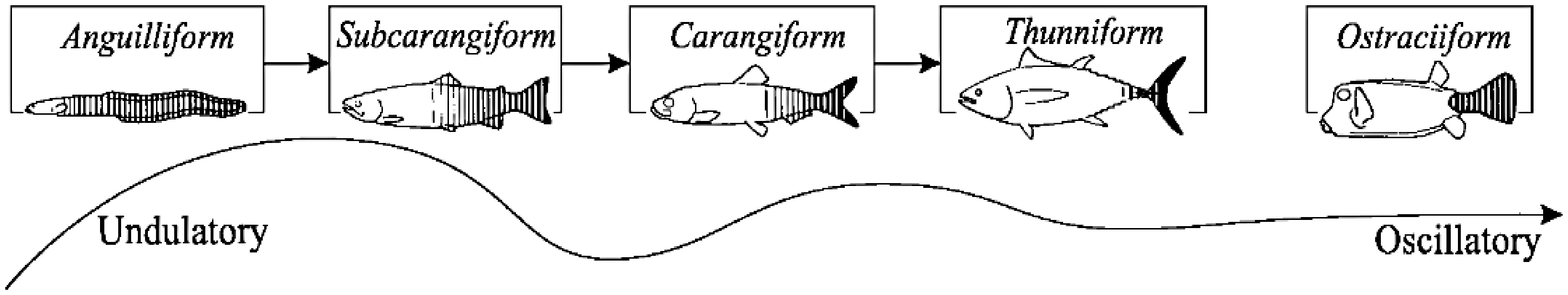


Construction of fish. Project focuses on the main body, dorsal fin, pectoral fins, anal fin and caudal fin.

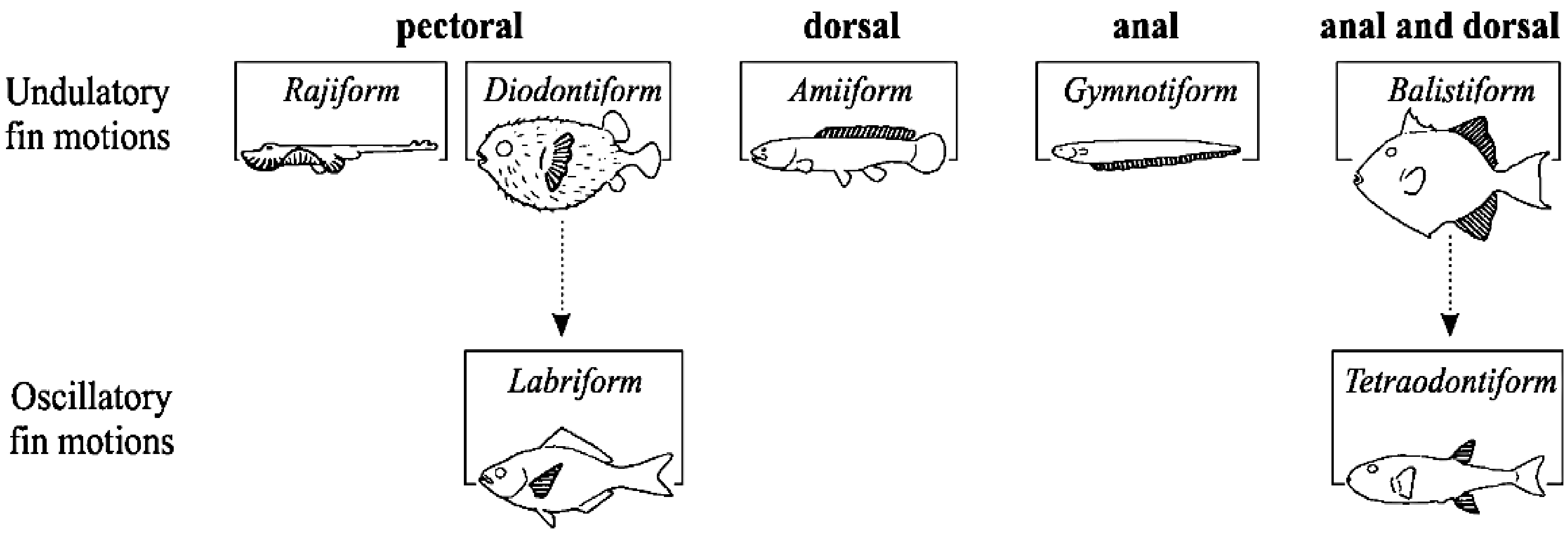
Sfakiotakis, Michael, David M. Lane, and J. Bruce C. Davies. "Review of fish swimming modes for aquatic locomotion." *Oceanic Engineering, IEEE Journal of* 24.2 (1999): 237-252.

Two general swimming modes:

BCF Mode (Body and /or Caudal Fin): eel, tuna, boxfish. Corresponding to serial cases.



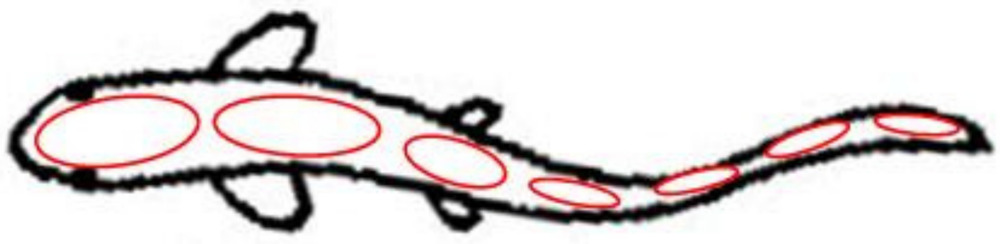
MPF Mode (median and /or Paired Fin) : pufferfish. Corresponding to tree-like cases.



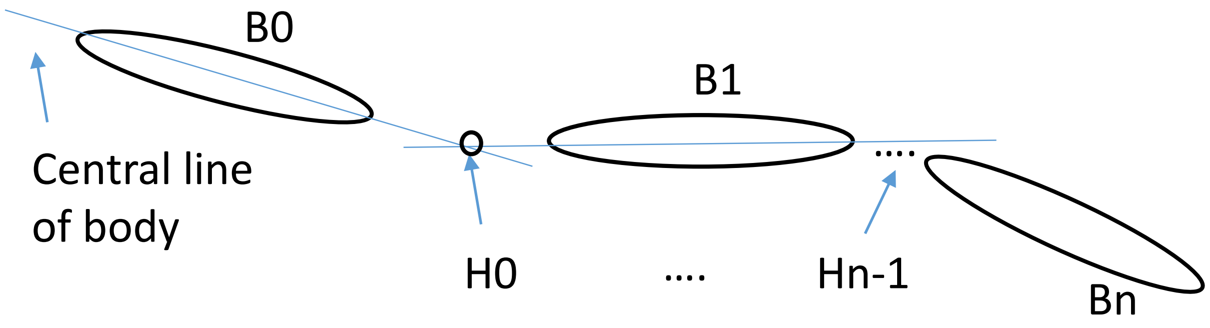
Sfakiotakis, Michael, David M. Lane, and J. Bruce C. Davies. "Review of fish swimming modes for aquatic locomotion." *Oceanic Engineering, IEEE Journal of* 24.2 (1999): 237-252.

Multi-body Dynamics Theory

- Split continuous body into several segments
- Number the segments from 0 to N
- Adjacent bodies are connected by a virtual hinge joint (number from 0 to N-1)
- Each body has own body-fixed coordinate
- Commercial software FLUENT used to solve flow field



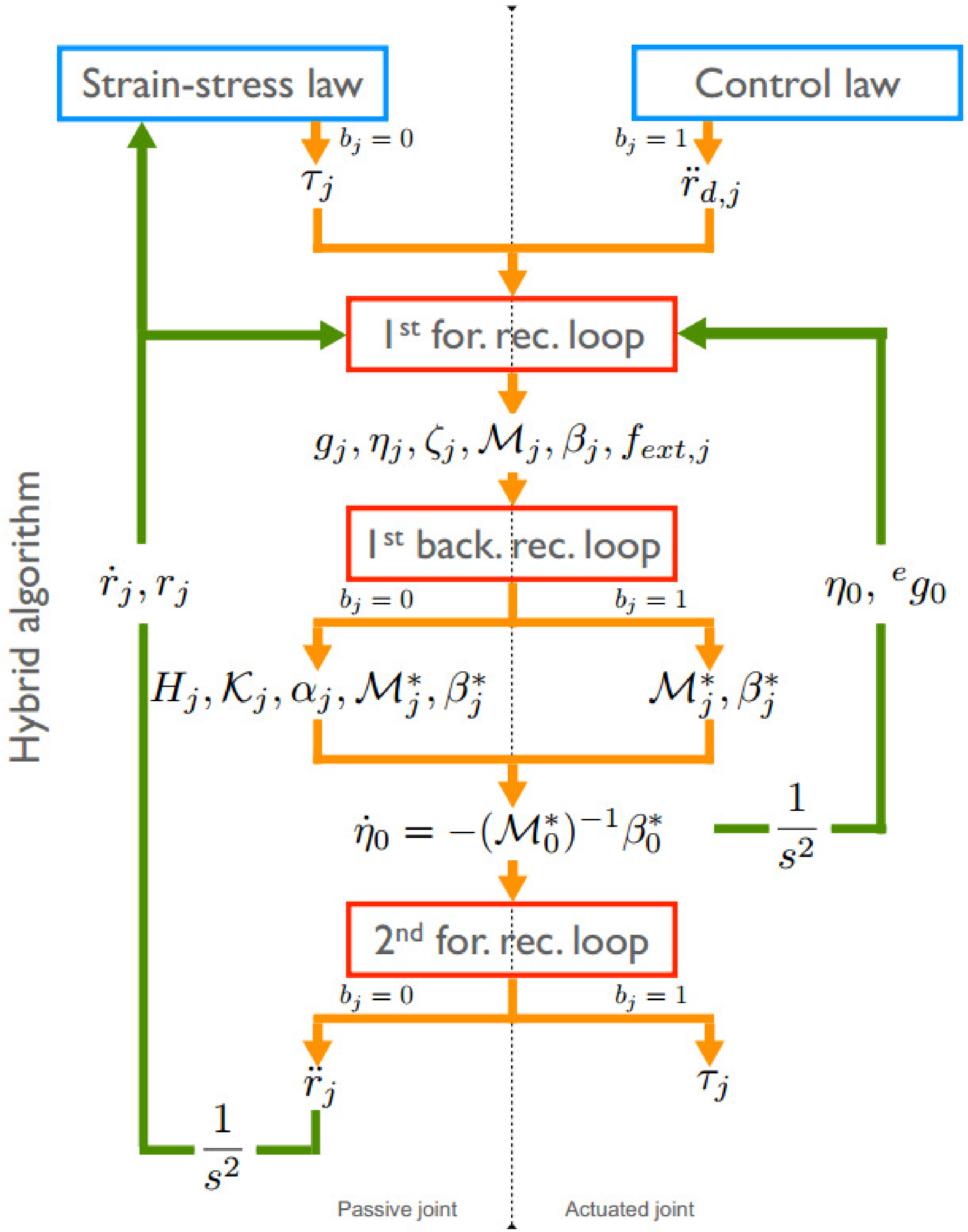
Current method to deal with flexible body



Schematic diagram of the fish model (serial case)

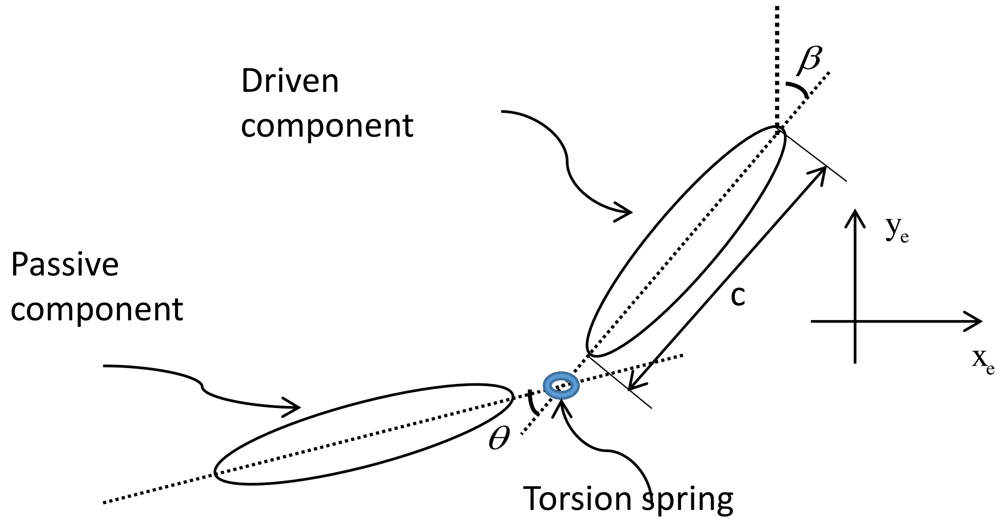
Algorithm

1. Two ways for input
   Strain-stress law :torque input; passive joint
   Control law : angular acceleration input; actuated joint
2. 1st forward recursion loop: information of each body under own body-fixed coordinate
3. 1st backward recursion loop :superimposed the information from the last body to the first body
4. Newton's Second Law :$\dot{a} = \frac{F}{M}$
5. 2nd forward recursion loop :calculated out angular acceleration/ torque of each hinge

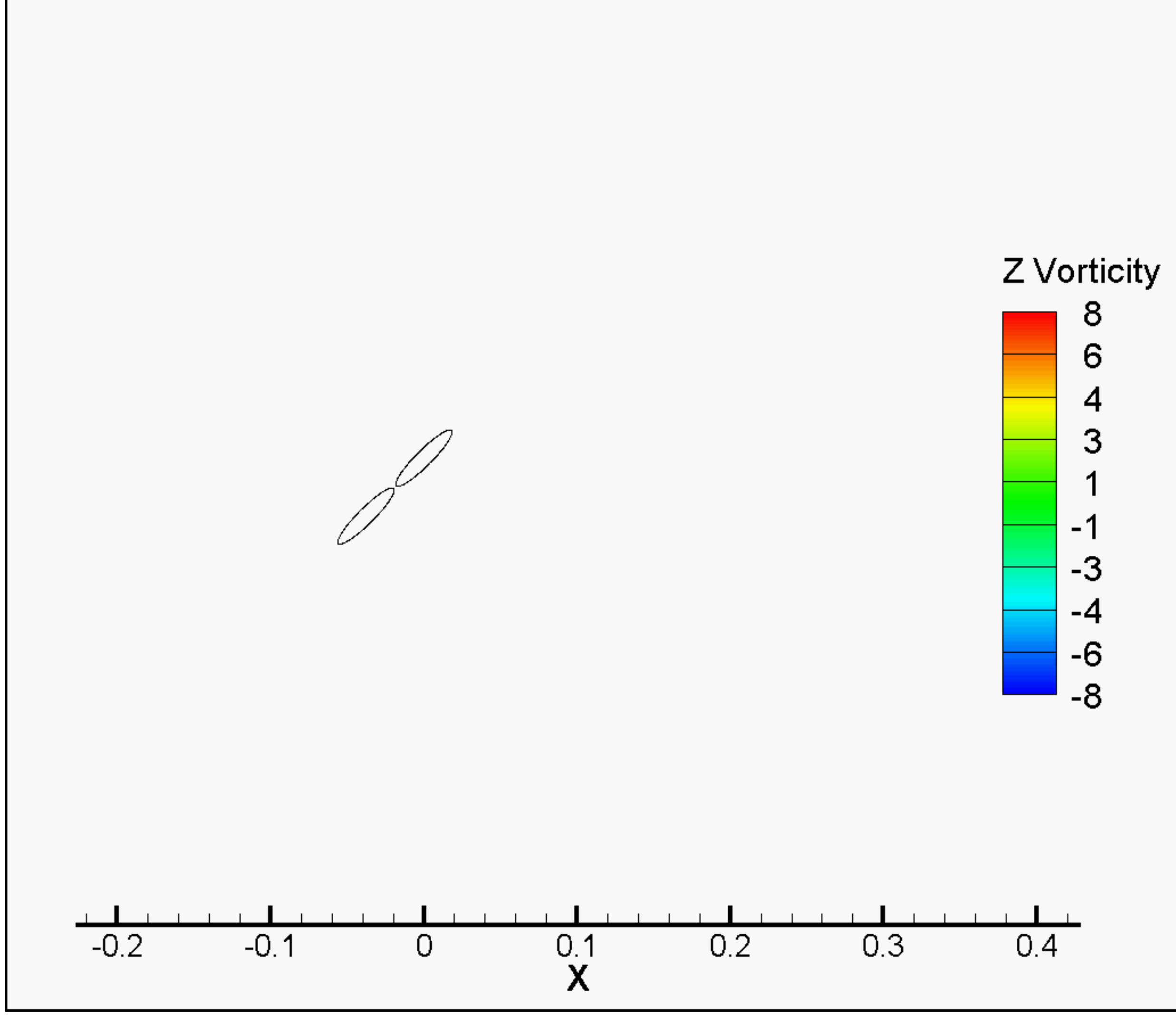


Porez, Mathieu, Frédéric Boyer, and Ayman Belkhiri. "A hybrid dynamic model for bio-inspired robots with soft appendages-application to a bio-inspired flexible flapping-wing micro air vehicle." *International Conference on Robotics and Automation*. 2014.

Validation case

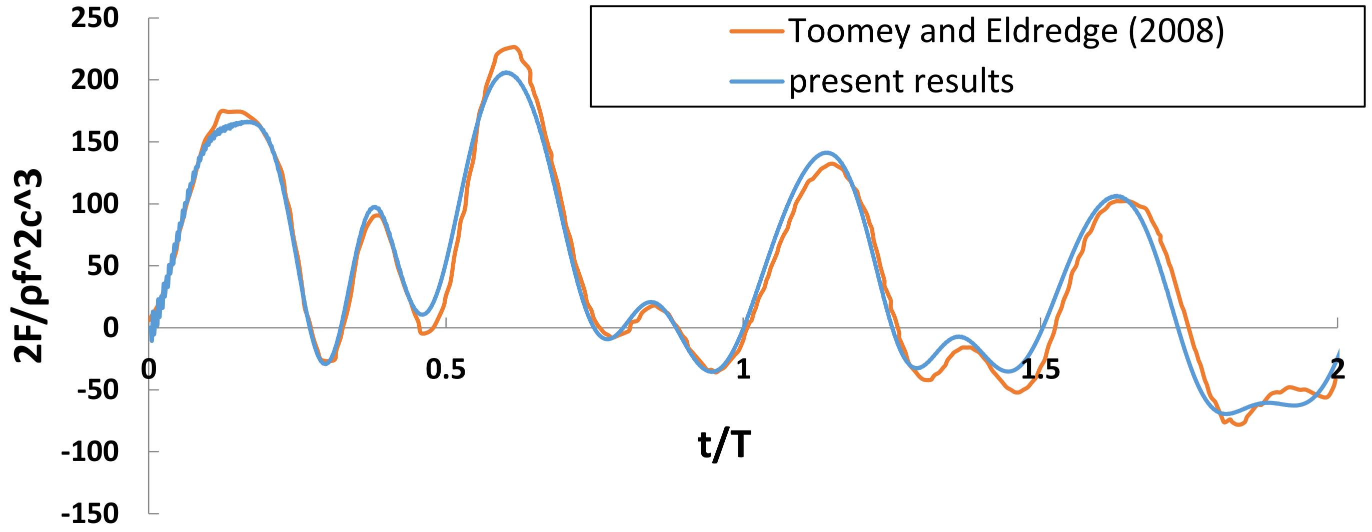


- Two-component wing structure connected by a single hinge with a damped torsion spring
- Prescribed translational and rotational motion on driven component

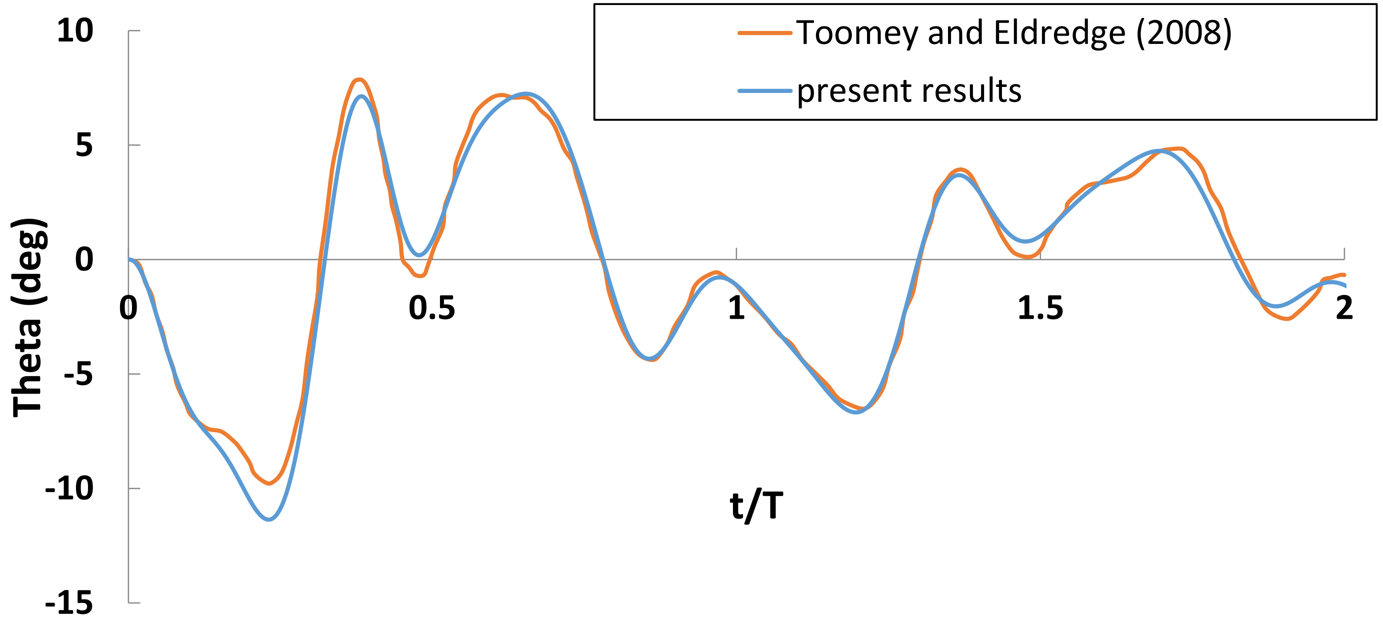


Jonathan Toomey and Jeff D. Eldredge. "Numerical and experimental study of the fluid dynamics of a flapping wing with low order flexibility." *Physics of Fluids (1994-present)* 20.7 (2008): 073603.

Results comparison



Dimensionless force comparison

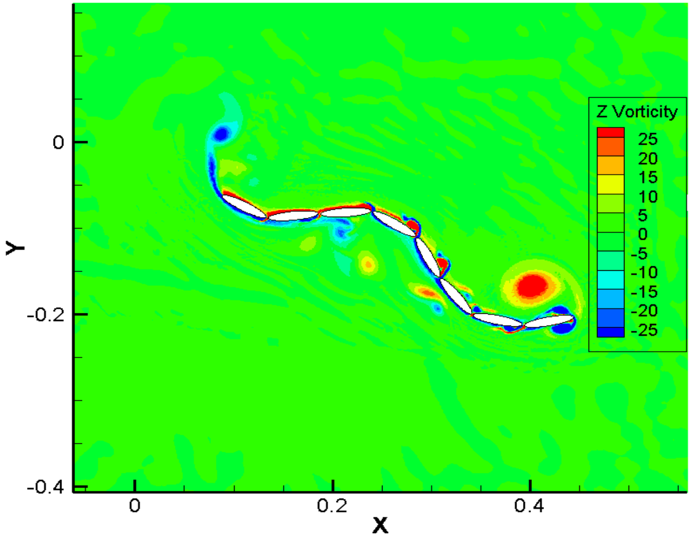


Hinge deflection angle

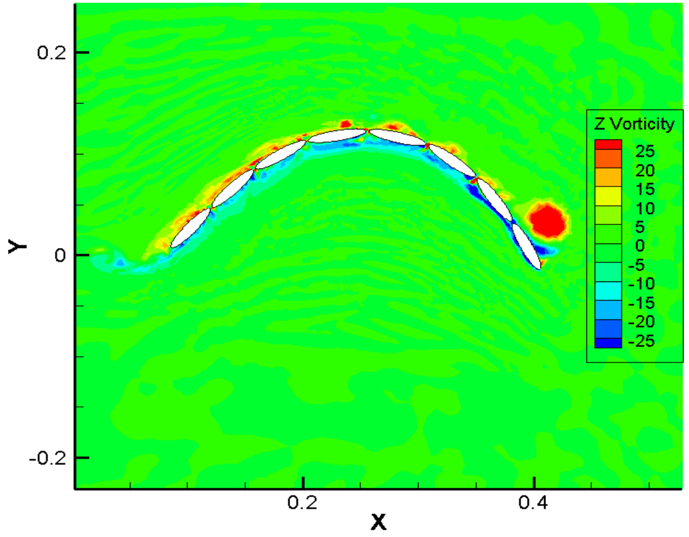
Jonathan Toomey and Jeff D. Eldredge. "Numerical and experimental study of the fluid dynamics of a flapping wing with low order flexibility." *Physics of Fluids (1994-present)* 20.7 (2008): 073603.

Serial cases

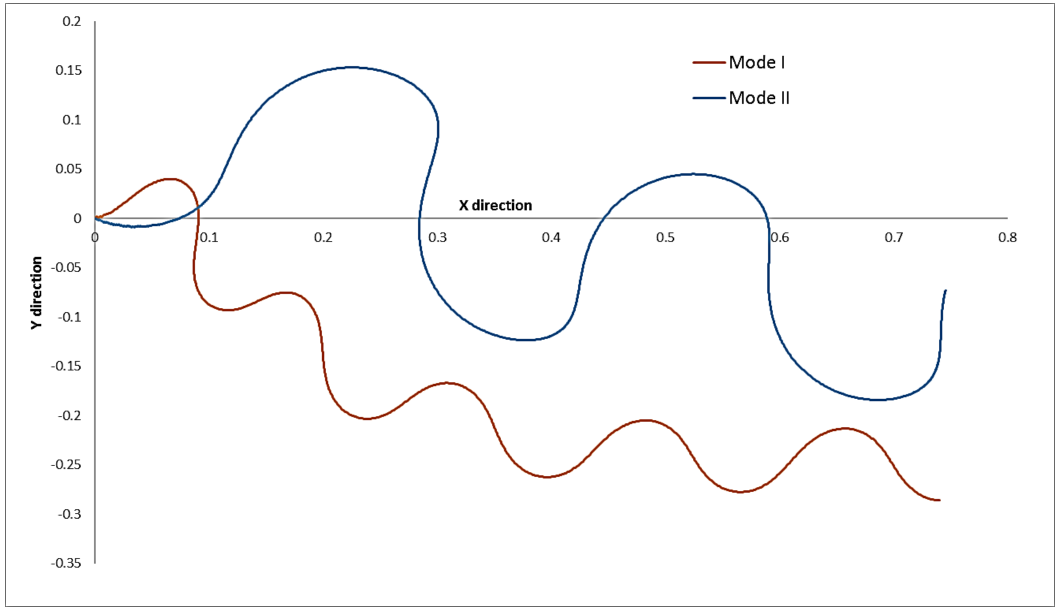
- Eight identical elements of fish model
- Gaps between each element is equal
- Two swimming modes
- Prescribed motions on hinges (Control law)



Mode I



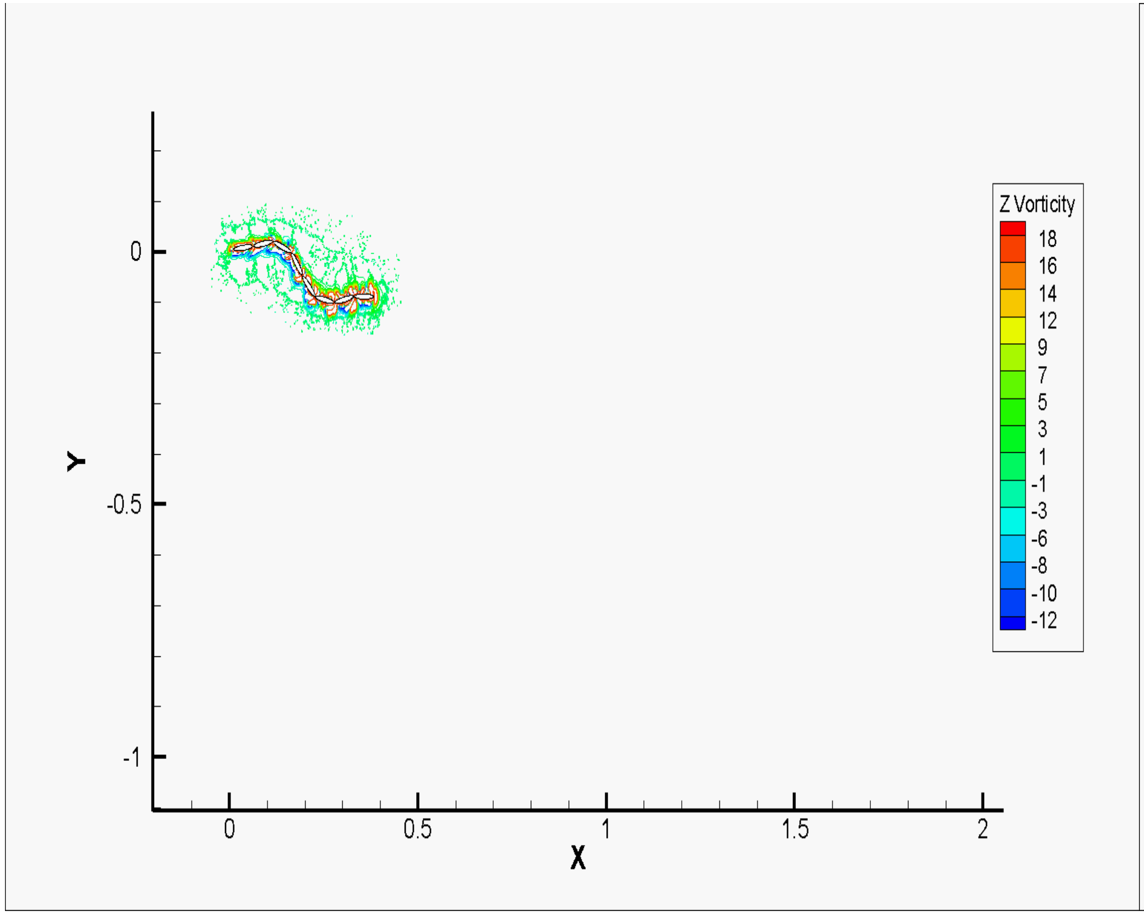
Mode II

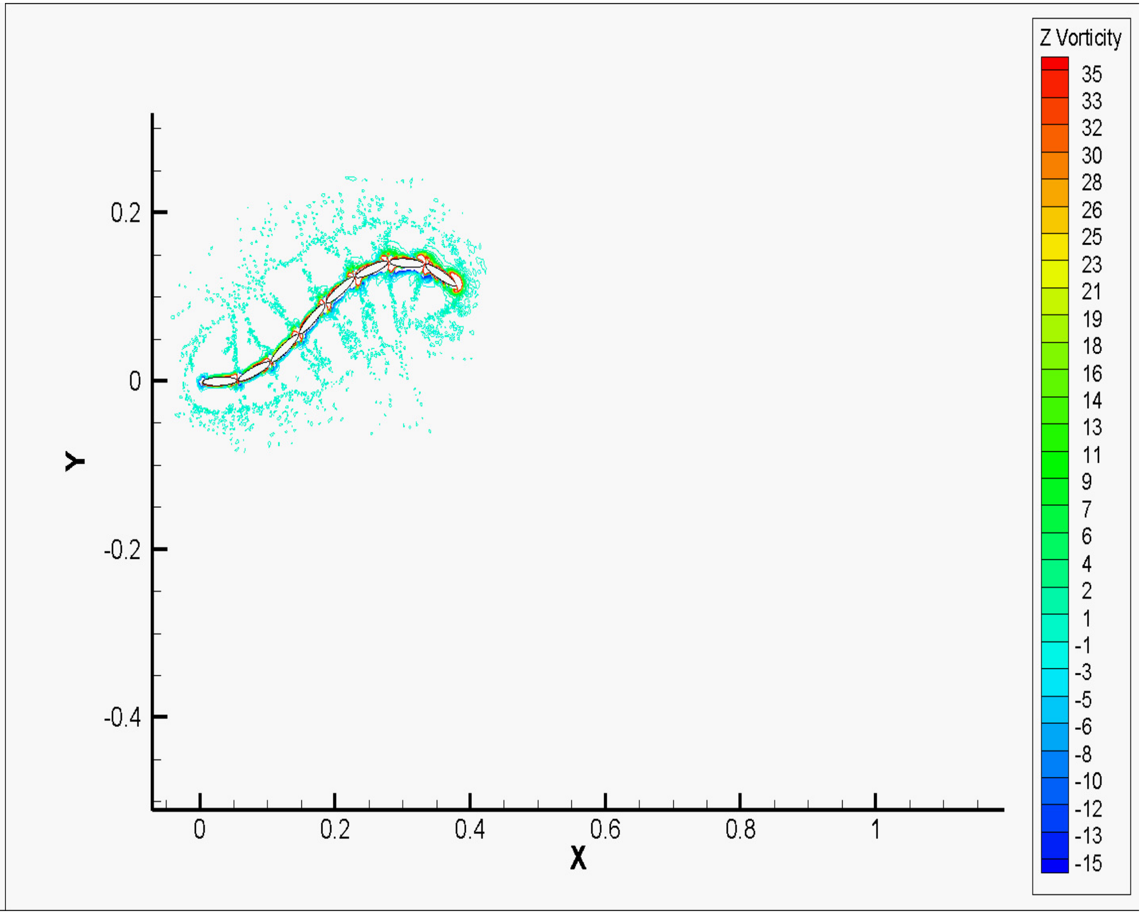


Predicted trajectories of two modes

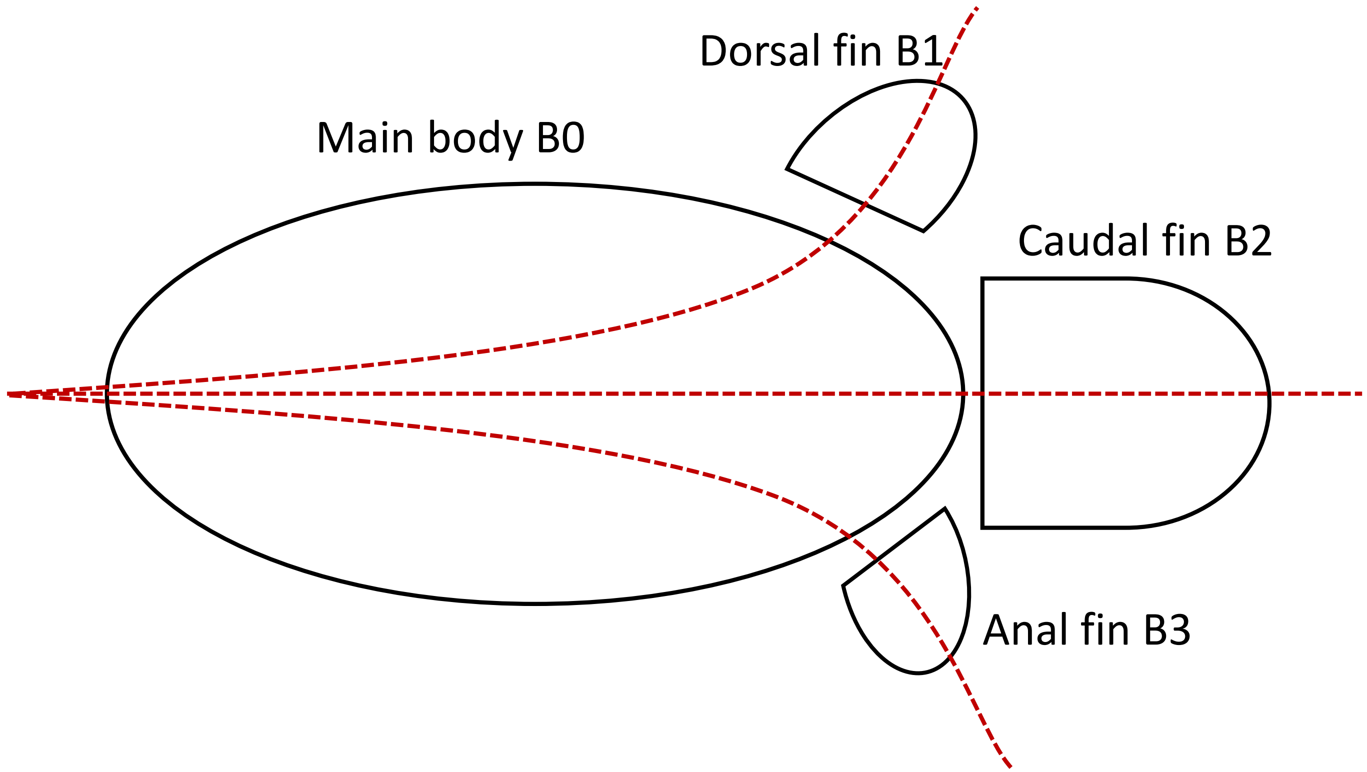
Porez, Mathieu, Frédéric Boyer, and Auke Ijspeert. "Improved Lighthill fish swimming model for bio-inspired robots-Modelling, computational aspects and experimental comparisons." *International Journal of Robotics Research* (2014): 1-34.

Different mode animations





Tree-like case

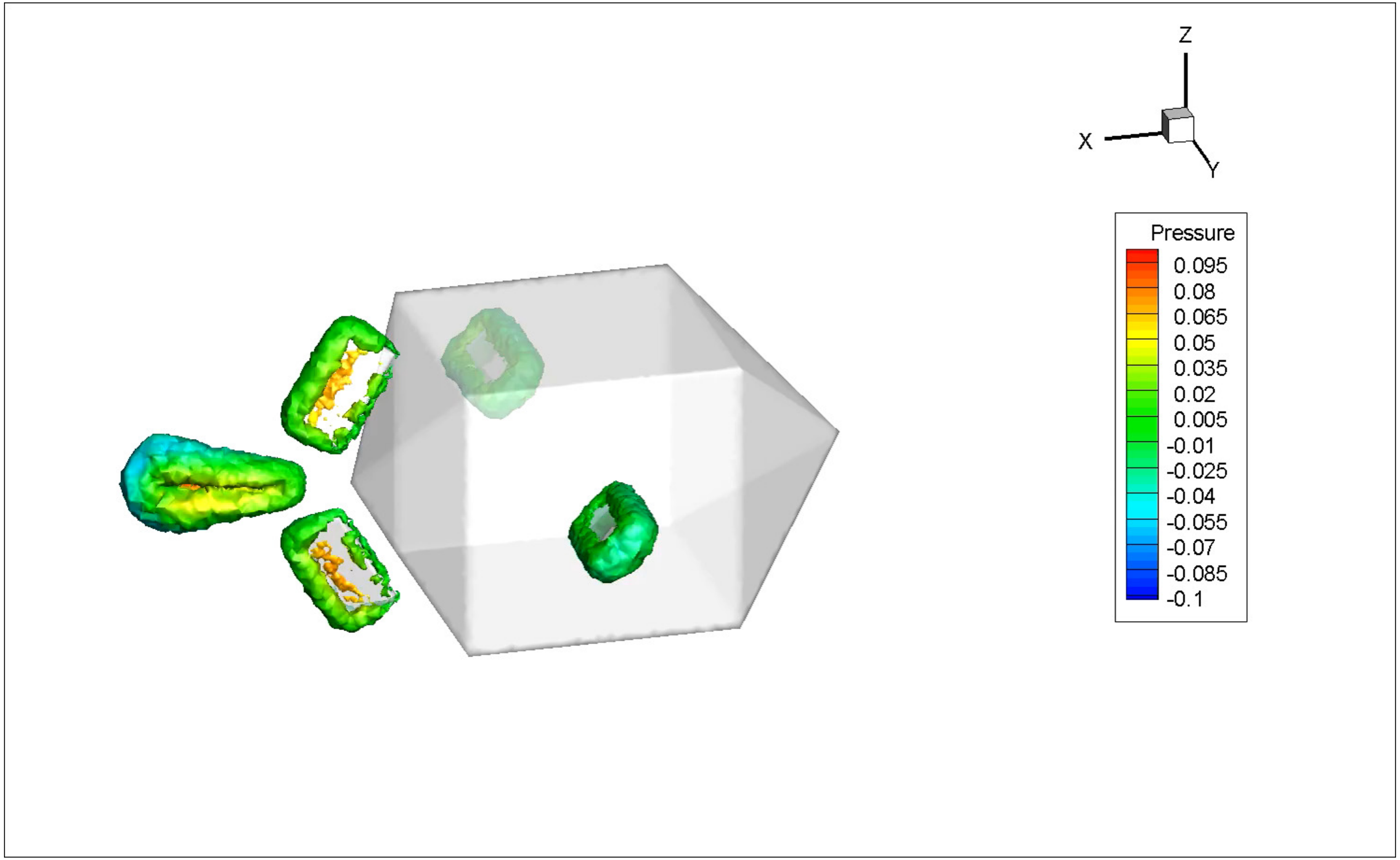


Sketch of a tree-like structure fish with dorsal, caudal and anal fin

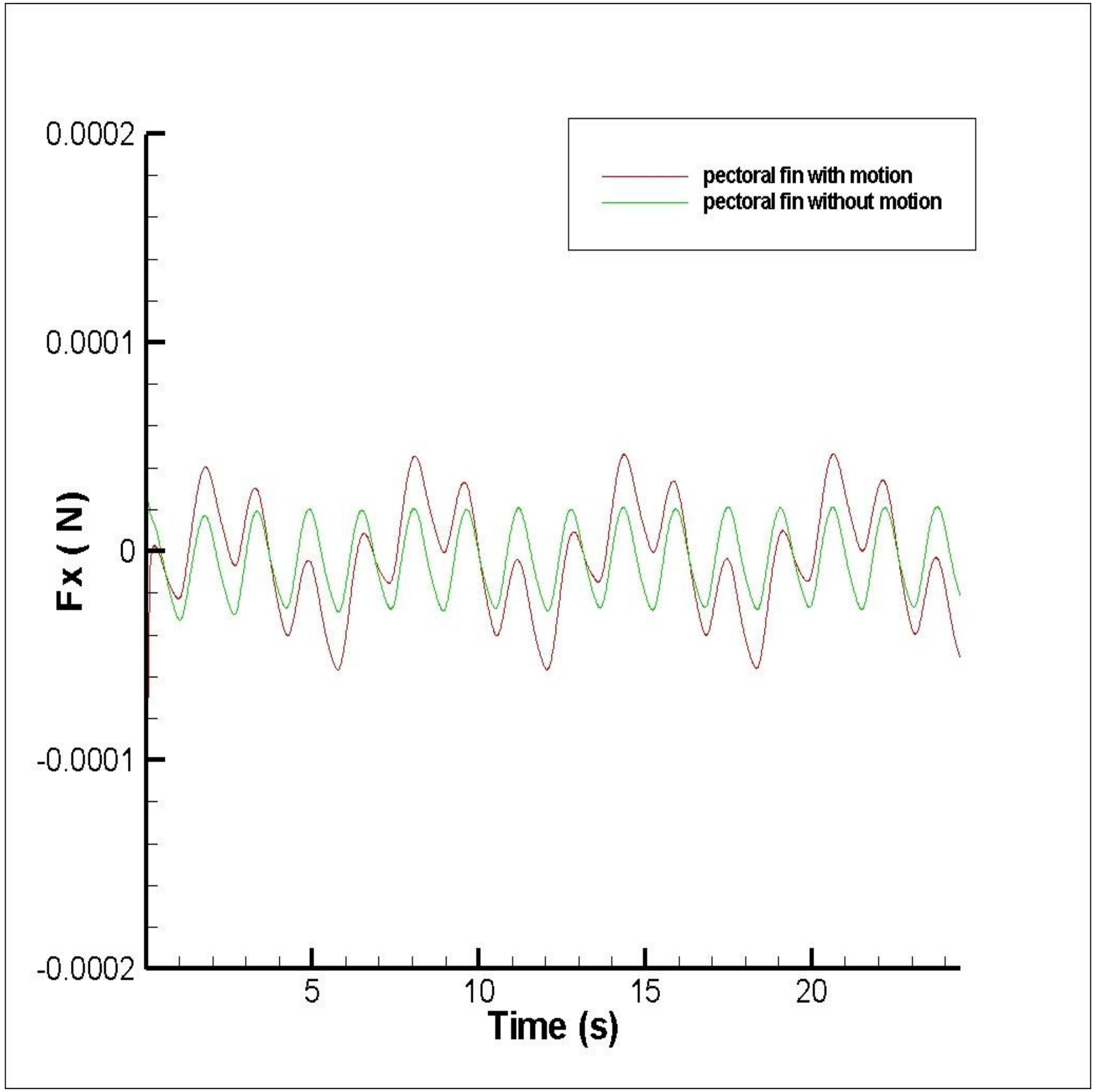
- Previous in-house code: only serial-structured multi-body function
- Current code status: tree-like function added
- Previous cases: 2D
- Current cases: 3D
- Application :fins can be taken into account (pectoral, dorsal, anal)
- Advantage :Self-propelled locomotion more fish-liked

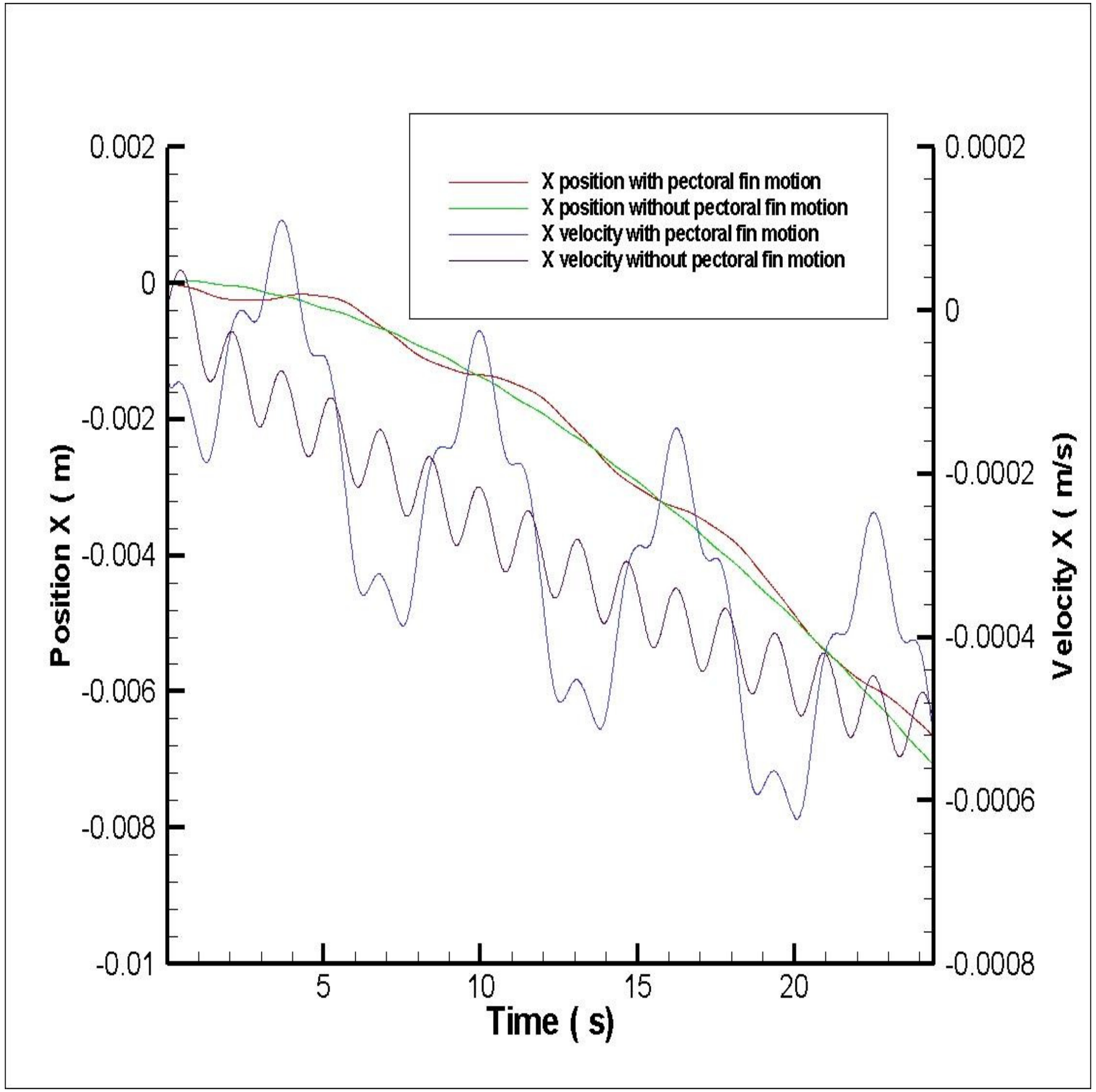
Boxfish

Pectoral, dorsal, caudal and anal fin flapping for self-propulsion



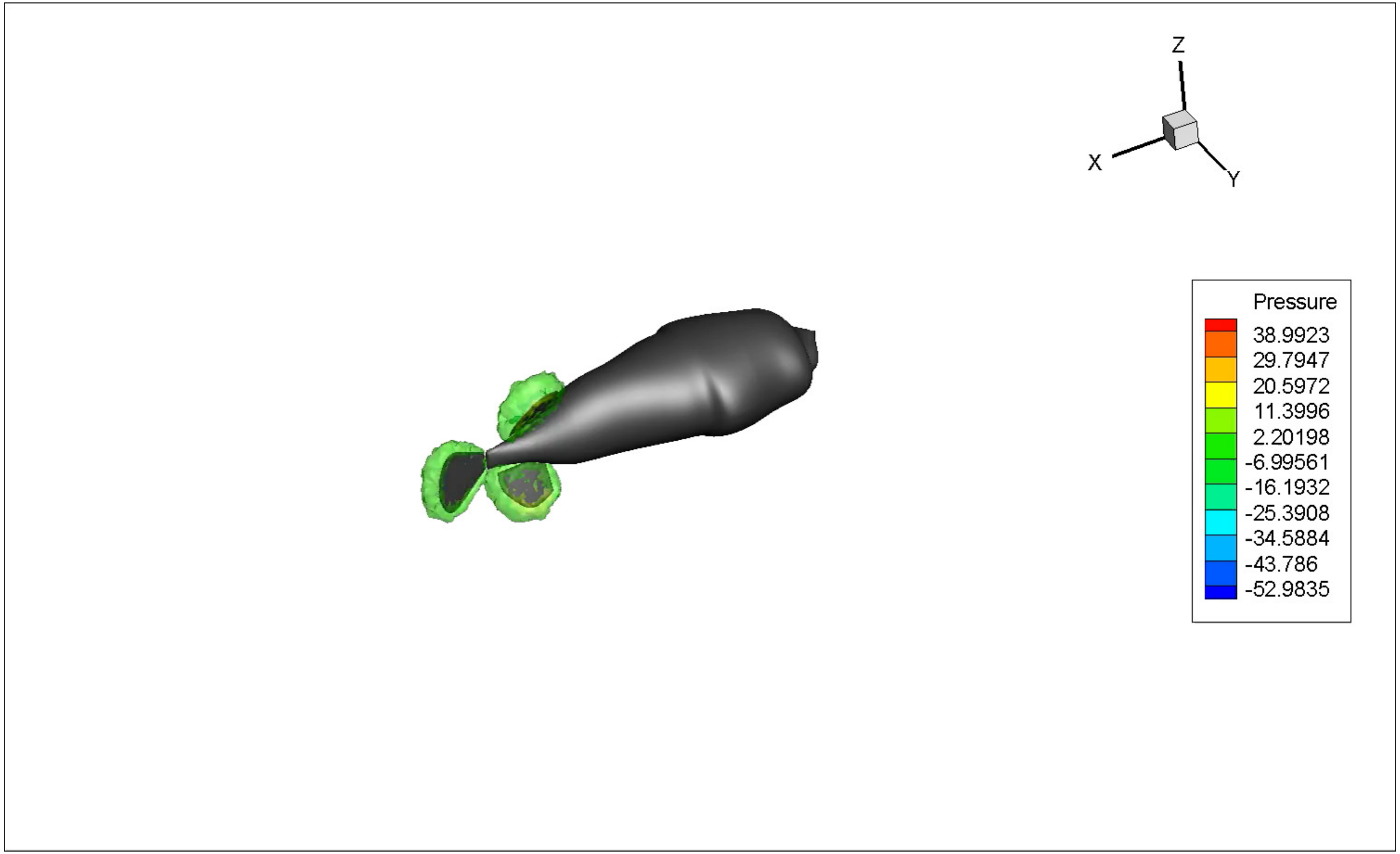
Partial results





Pufferfish

Dorsal, caudal and anal fin flapping for self-propulsion



Thank you!