Hydrobatics for Underactuated AUVs

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Towards exploiting the dynamics of the surrounding water

Examples from nature demonstrate the potential of exceeding stable flow regimes and exploiting turbulent flow.

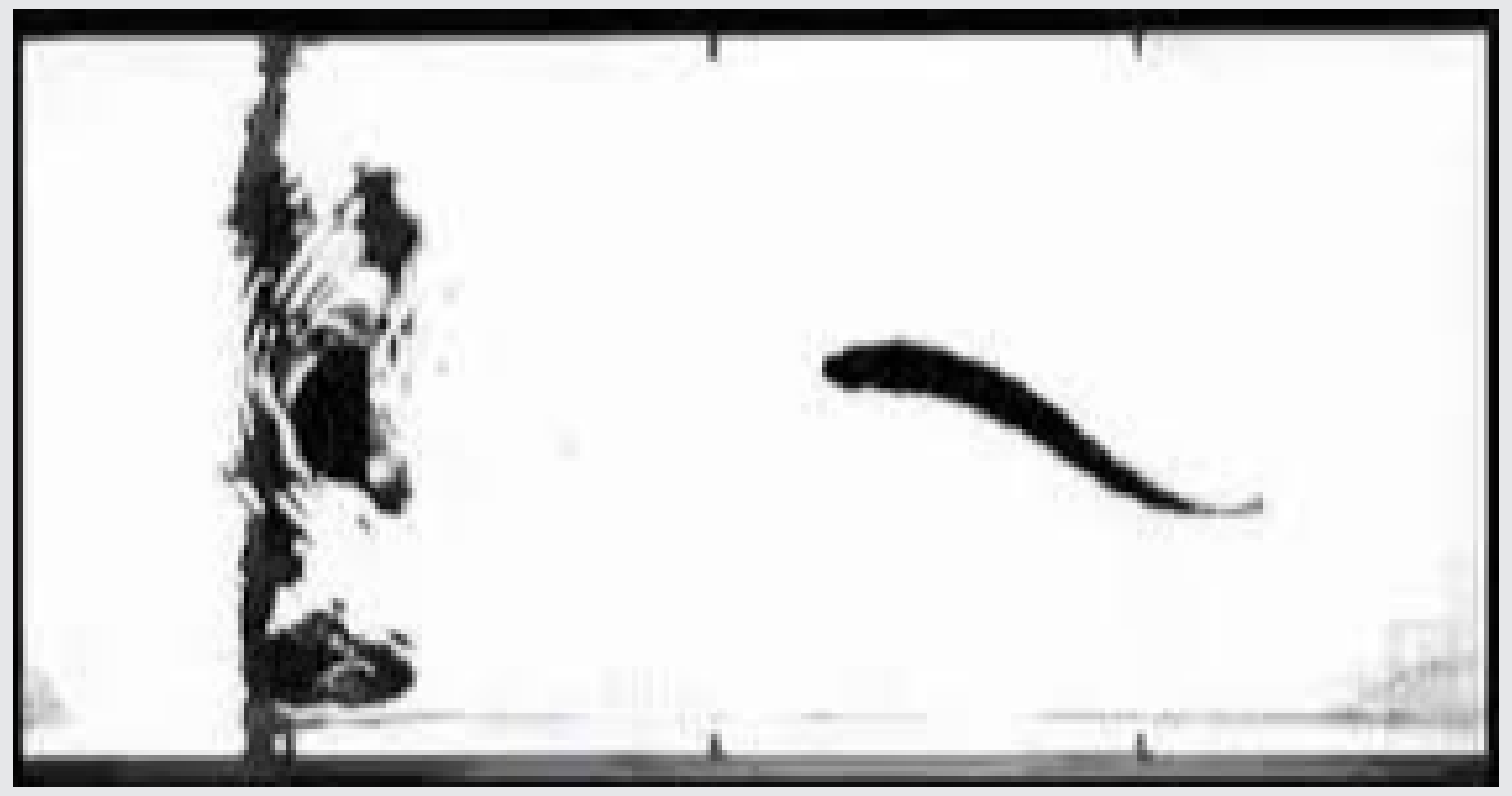

Figure: Dead trout swimming upstream in turbulent flow [1]

Current control approaches lack the capability to use knowledge about hydrodynamics to improve performance. Closing this gap is essential for performing Hydrobatics with *AUVs*.

Hydrodynamics in control

To apply model-based controllers to underwater robots, an appropriate hydrodynamic model is needed. A precise model could be obtained by numerically solving the Navier Stokes equations[2], but this is not real-time capable. Hence, one has to look at approximate approaches that allow online computation of the drag forces. Fossens model[3] offers a compact formulation that can be obtained by model identification.

Changing flow regimes

The drag coefficients of submerged bodies change with regard to the flow regime of the surrounding water. The hydrodynamic model therefore changes with the executed maneuver. As a step towards better execution of Hydrobatics, we will use a local model for each class of maneuver.

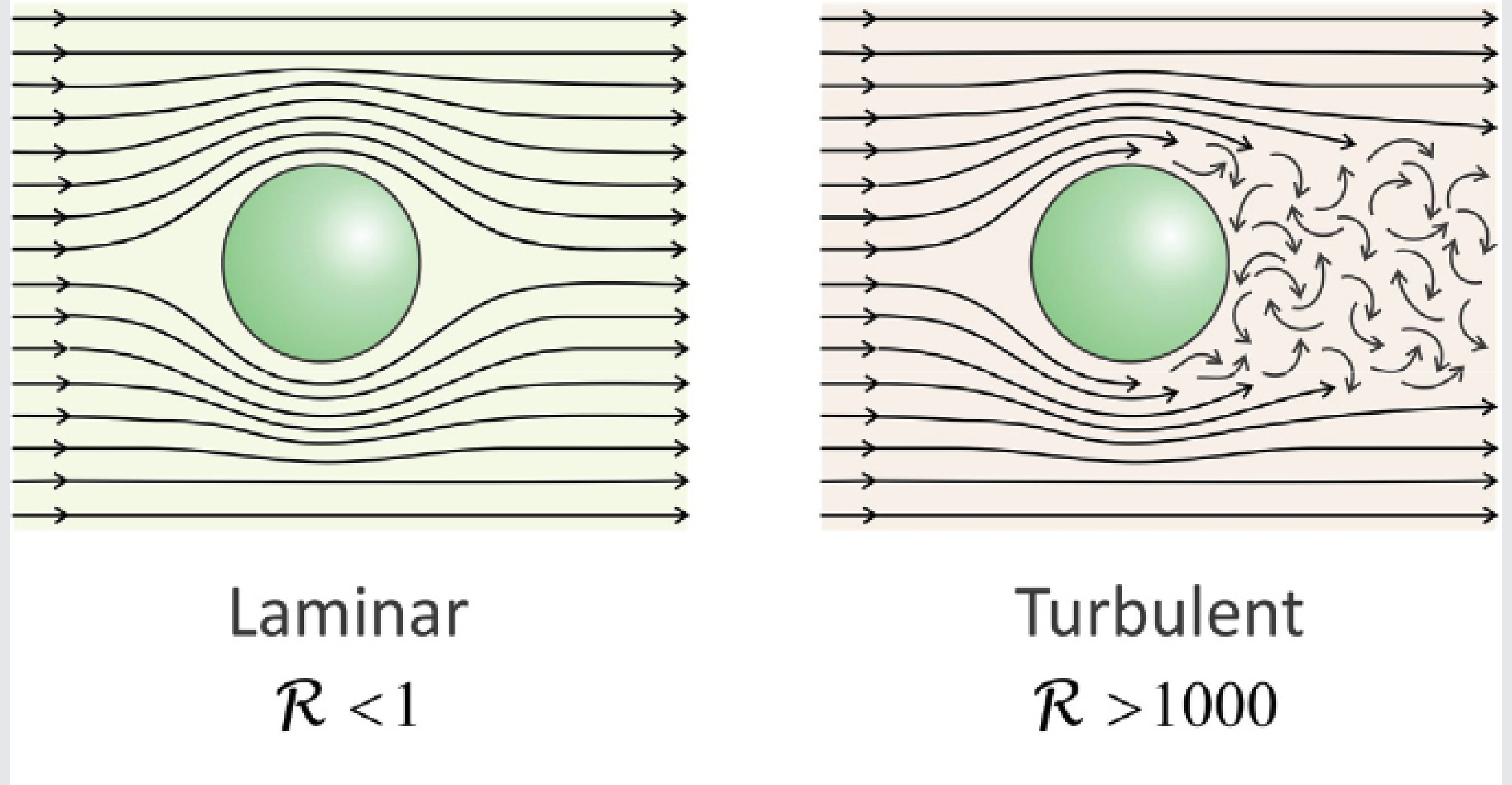

Figure: Visualization of the flow regimes and their typical Reynold numbers [4]

DeepLeng

Figure: *DeepLeng AUV* demonstrating the vectored thrust during under-ice deployment in Abisko, Sweden [5]

In the *EurEx-LUNa* project *DeepLeng* was developed for the exploration of one of Jupiter's ice-covered moons, *Europa*. Fitted in the cargo space of a robotic probe that drills through the ice crust, it is deployed into the underlying ocean to explore and collect samples [6].

A long range is vital for this mission, leading to the AUV's torpedo-shaped design to minimize drag. At times it has to perform agile maneuvers, e.g., to inspect walls or for vertical docking.

Vectored Thrust

DeepLeng is only propelled by a single thruster mounted to the main body by a pan tilt unit. The mechanism is very stiff, but the maximum angular speed of the thruster is rather slow.

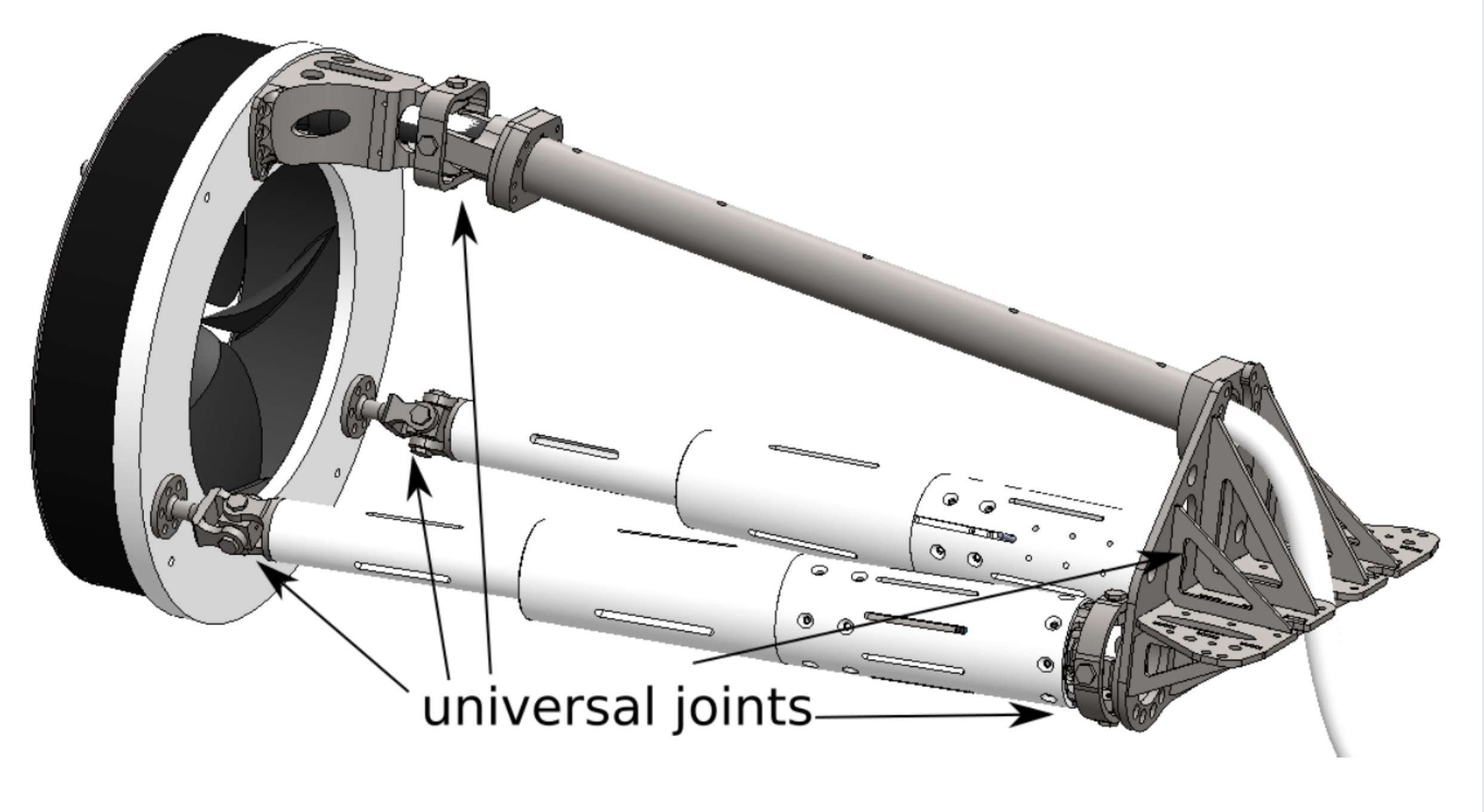

Figure: Pan-tilt unit of *DeepLeng*

This propulsion concept leads to the *AUV* being underactuated. The maximum angular speed of the thruster is rather slow, demanding predictive control.

On the upside, a larger and more energy-efficient thruster can be installed compared to a fully actuated approach with multiple thrusters outside the hull.

Control strategy

We will use Trajectory Optimization and a time-varying LQR to stabilize around the generated trajectories. Before the execution of a maneuver, the controller is initialized with the associated model.

Trajectory Optimization

Physically feasible trajectories are generated by defining a nonlinear optimization problem. Direct transcription is used to generate a set of states and actuator inputs in a time interval which will be the decision variables. The dynamics are respected by defining an equality constraint with the equation of motion. This way, not only the manipulator equations, thus the generalized forces applied by the thrust force and the rotation of the thruster, but also hydrodynamic drag and restoring forces are enforced.

Trajectory Stabilization

Since the Trajectory Optimization alone is an open-loop controller, an additional controller is needed to stabilize around the trajectory to compensate for modeling errors besides other sources of error.

Linearizing around the states and inputs on the trajectory and interpolating them yields a time-varying linear system for which an LQR can be computed. This technique is known as time-varying LQR. The hydrodynamic model can also be incorporated into the model of the controller to enhance performance.

Polebalancing

As an example, we will consider the polebalancing maneuver.

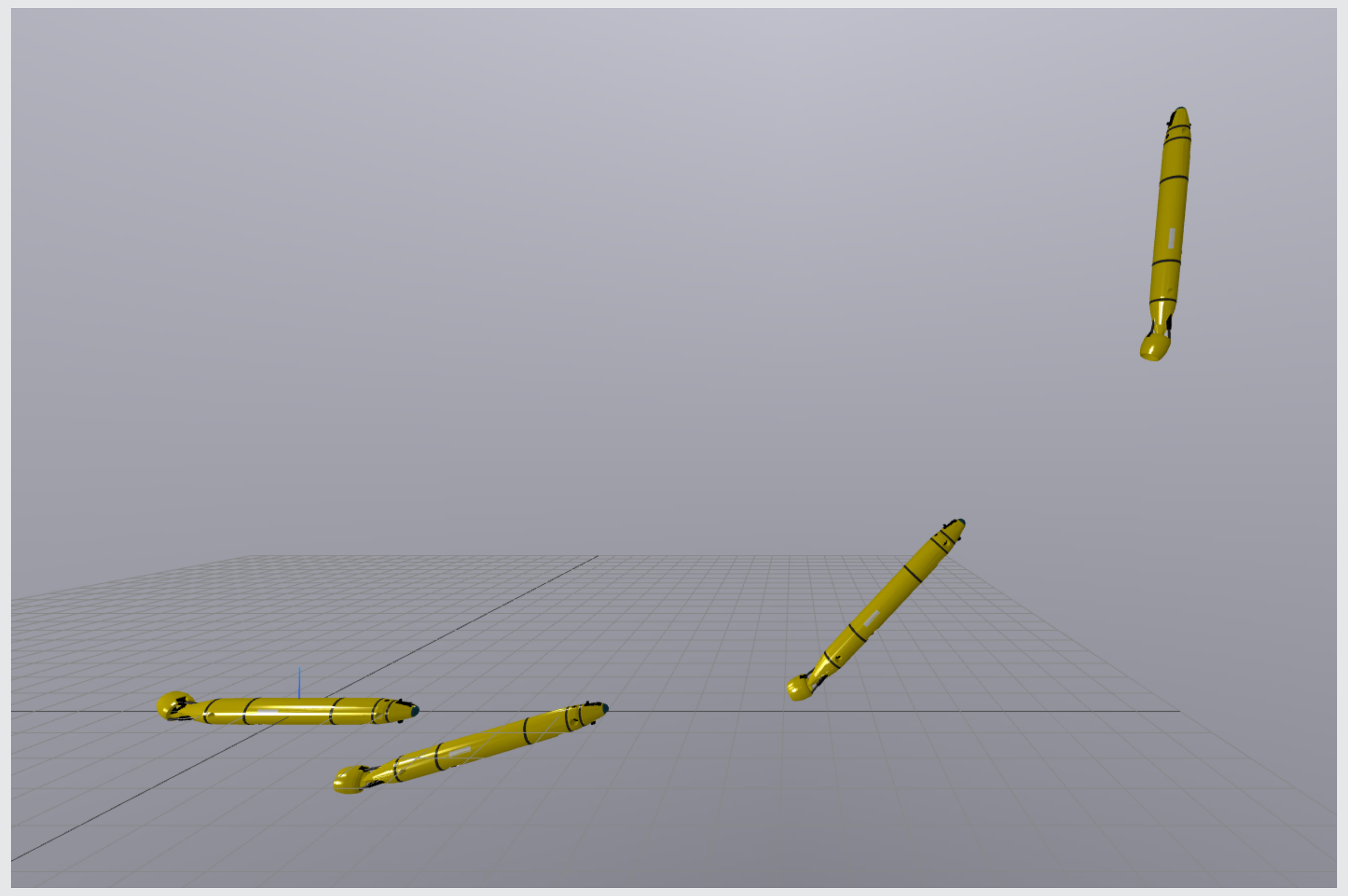

Figure: Time lapse of the pole balancing maneuver

The solver finds a trajectory where after fifteen seconds a 90° pitch is reached and then maintains the orientation for the last 5 seconds of the trajectory.

Simulation results

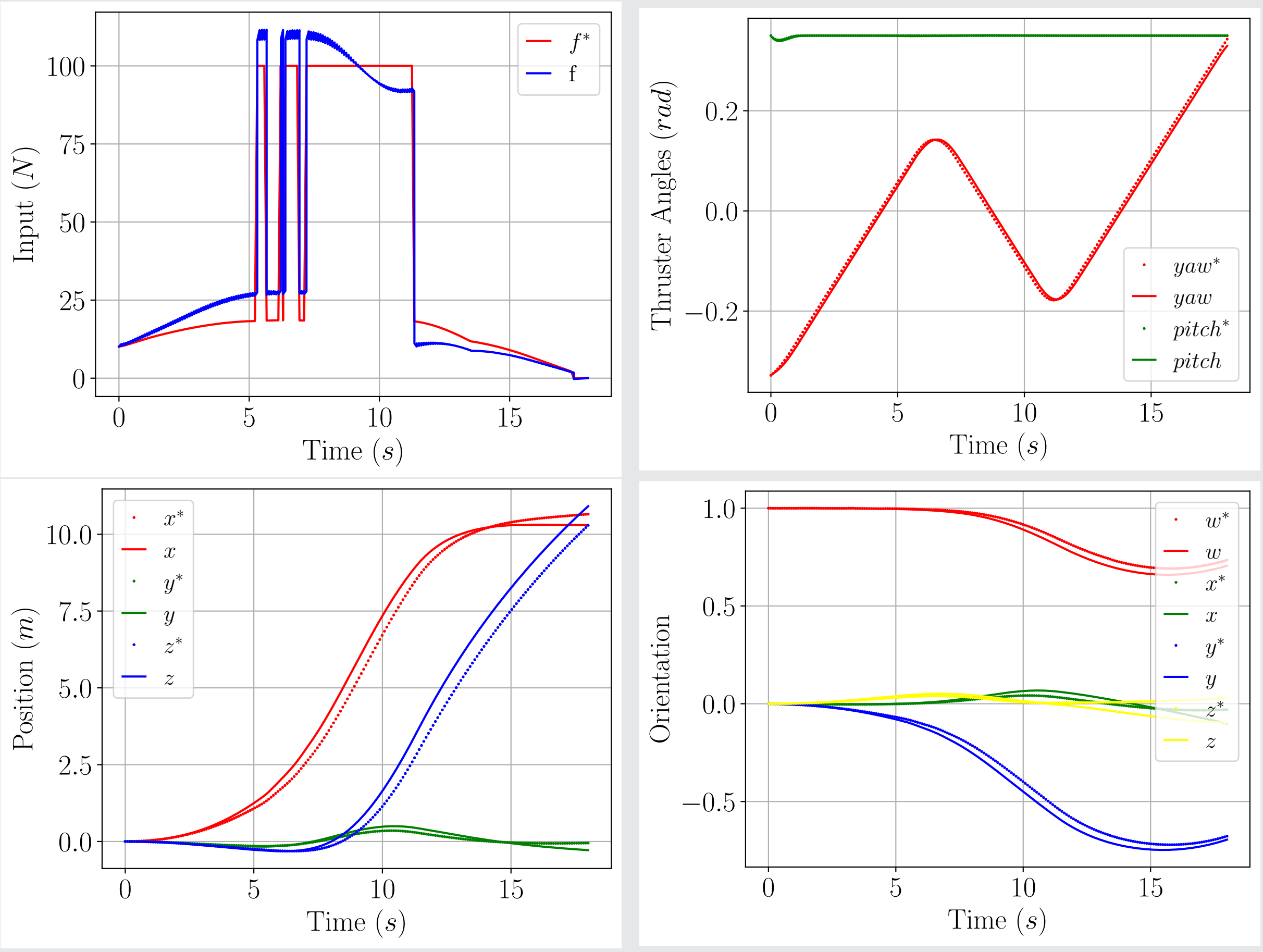

Figure: The force input(top left), thruster angles(top right), position(bottom left) and orientation(bottom right) during execution of the pole balancing trajectory in a simulation

Future Work

An online model adaptation will be added to estimate the parameters of the hydrodynamic model during the execution of a trajectory. After finishing the maneuver, the respective model of that maneuver is updated. This way, the models converge to the locally optimal coefficients. Not only could this solve the problem of the changing flow regimes for the different maneuvers, but also allows the system to adapt to a changing environment.

Acknowledgment

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References

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