Shape Optimisation for Dynamic Fluid-Structure Interaction Problems

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Introduction

Both wind turbines and airborne wind energy systems experience fluid-structure interactions (FSI). This project will use transient shape optimisation (Fig. 1) to enhance the aerodynamic performance of these and other devices. This is equivalent to adopting a passive control strategy [1], which may be advantageous for applications where it can be used in conjunction with, or in place of, an active control system.

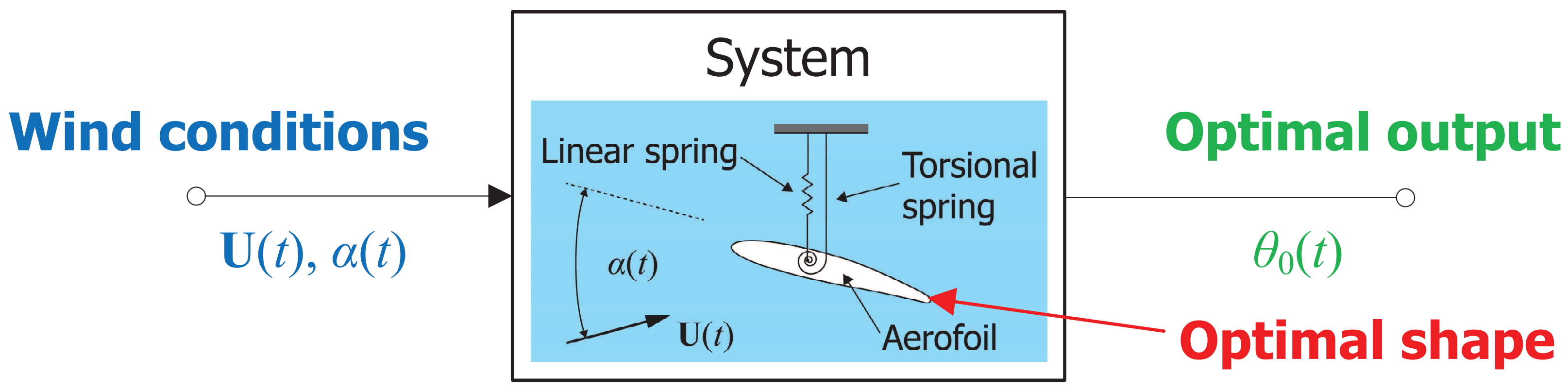

Figure 1: In transient shape optimisation, the shape of the blade is specified before operation so that its performance is optimal, on average, for the duration of the transient load.

Development of Lagrange Multiplier Formulation

The FSI simulation tool used (Fig. 2) consists of the computational fluid dynamics (CFD) solver, Fluidity [2], coupled to a rigid-body dynamics solver that describes geometry using non-uniform rational basis splines (NURBS). Originally, the tool utilised an immersed boundary method [2] in which the CFD mesh extends into the structure, which is represented using a penalty body force. A distributed Lagrange multiplier (DLM) body force has been added to the tool as an alternative method. A comparative analysis was carried out to assess both formulations.

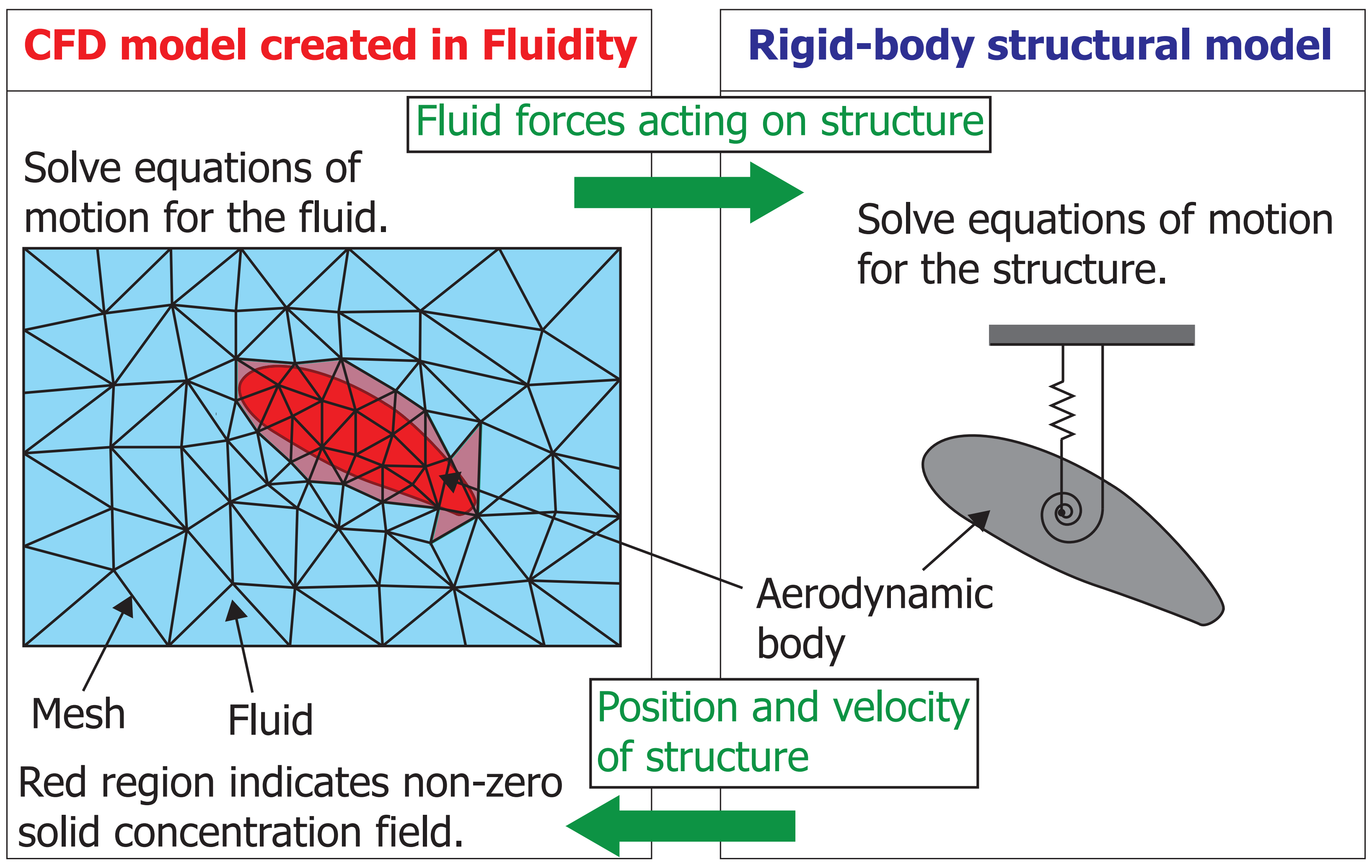

Figure 2: FSI simulation tool developed during the project.

Comparative Analysis: Flow Between Two Walls

The penalty and DLM formulations were compared by analysing the laminar flow between two walls seperated by a distance $D = 1$ m. The defined body approach, in which the CFD mesh only covers the fluid domain, was used as a benchmark. The solution from the DLM formulation was almost identical to the benchmark (Fig. 3). In contrast, the penalty body force produces a flow field that lags behind the other two, but still reaches a similar steady state. The penalty body force fails to accurately impose the no-slip boundary condition at the walls and underpredicts the pressure drop (Fig. 4).

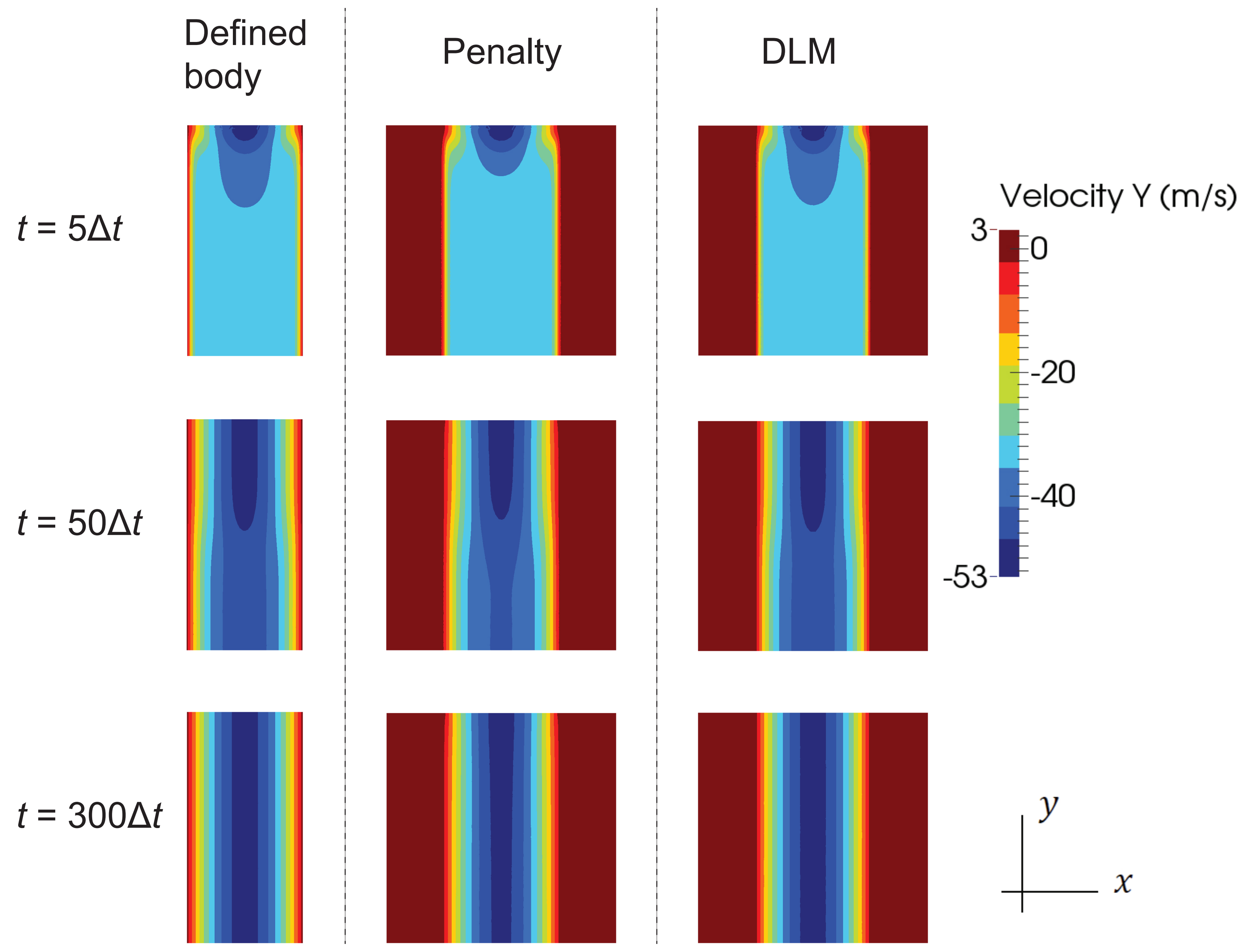

Figure 3: Velocity field for the defined body, penalty and DLM approaches. $Re = Dv_{\text{avg}}/\nu = 33.3$, $\nu = 1$ m^2/s, $\Delta t = 0.001$ s.

Conclusions and Future Work

A DLM formulation has been added to the FSI simulation tool. For the problem analysed, this formulation was more accurate than the penalty body force originally used by the tool. Each formulation is currently being tested on a FSI problem featuring a moving body. Eventually, the tool will be combined with a transient shape optimisation algorithm, which will be used to improve the shape of aerodynamic bodies for unsteady conditions.

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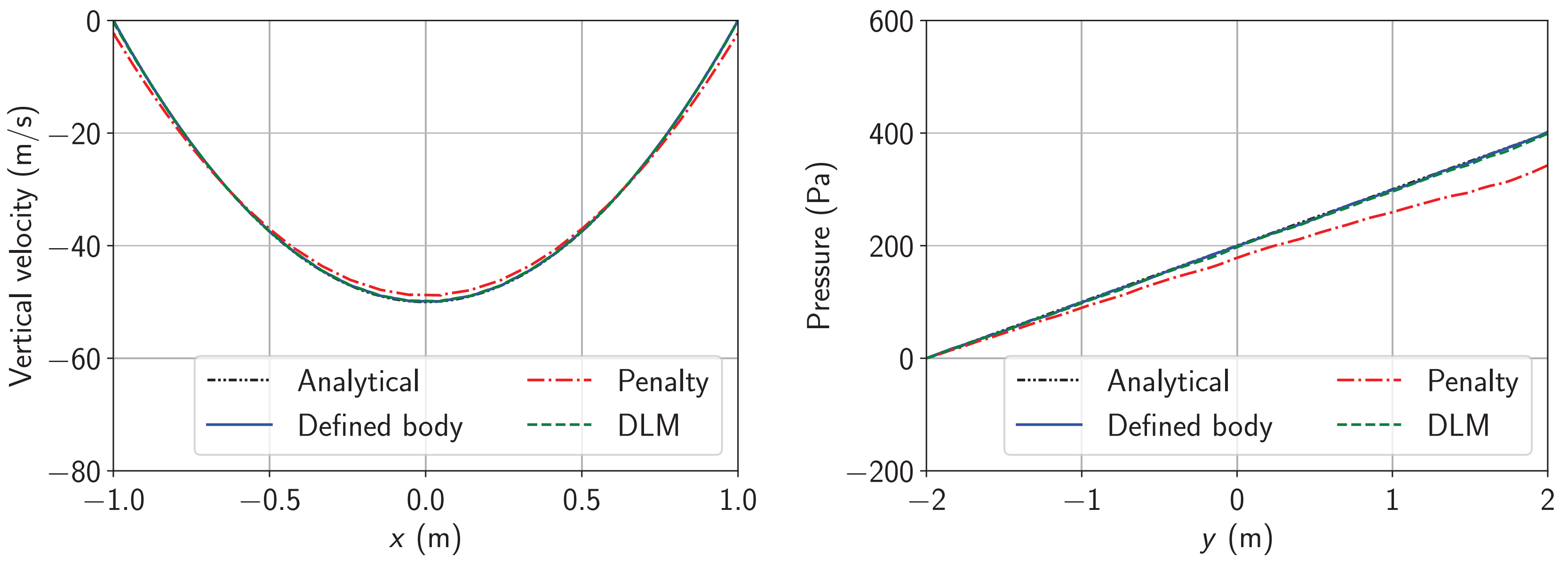

Figure 4: Velocity at the outlet of the channel, and pressure along its centerline from outlet ($y = -2$ m) to inlet ($y = 2$ m). $Re = Dv_{\text{avg}}/\nu = 33.3$, $\nu = 1$ m^2/s, $\Delta t = 0.001$ s.

References

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MSc/PhD/Postdoc progress

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