Experience Report of Physics-Informed Neural Networks in Fluid Simulations: Pitfalls and Frustration

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How Do PINNs (Physics-Informed Neural Networks) Work?

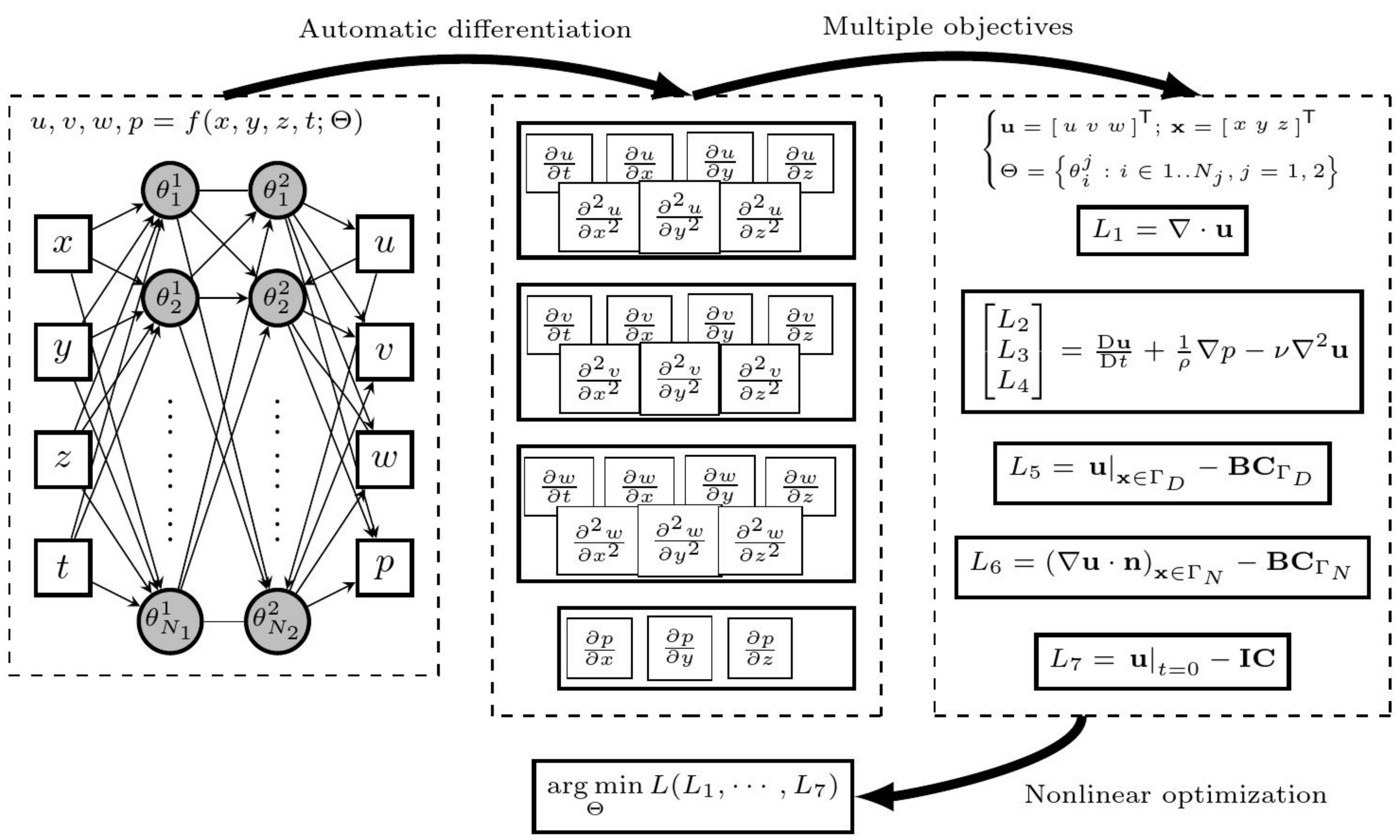


Fig 1. Graphic illustration of PINNs

Study Overview

Study Aim

To understand the

1. feasibility of PINNs in practical engineering: controllability and predictability w.r.t. cost and accuracy, and
2. possibility of replacing traditional CFD solvers w/ PINNs.

Key Findings

1. No obvious ways to control accuracy: no obvious translation from training loss to prediction errors
2. No obvious ways to predict time-to-solutions
3. Weak-scaling efficiency is good, but weak scaling does not help the accuracy nor the time-to-solution
4. Cost-performance ratio not competitive w/ traditional CFD solvers
5. Not able to solve a simple vortex-shedding problem

Limitations and Disclaimer

1. We only consider the data-free applications of PINNs.
2. We did not exhaust all possible architectures and configurations. The qualitative findings only apply to the specific configurations we tried.

Acknowledgement

We appreciate the support by NVIDIA, through sponsoring the access to its high-performance computing cluster.

Cost-Performance Benchmarking w/ a 2D Taylor-Green Vortex Problem

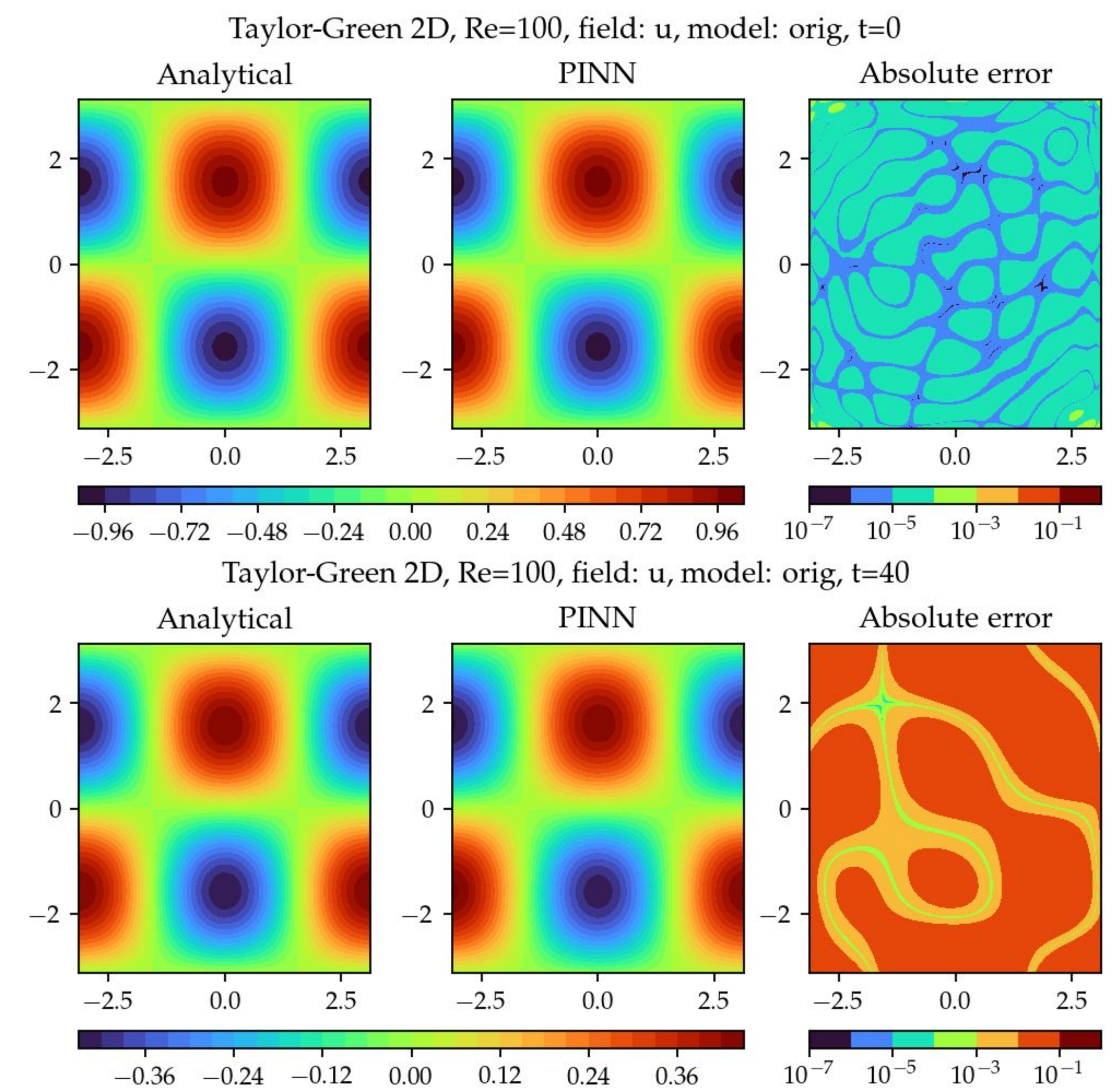


Fig 2. Contours showing degraded temporal accuracy

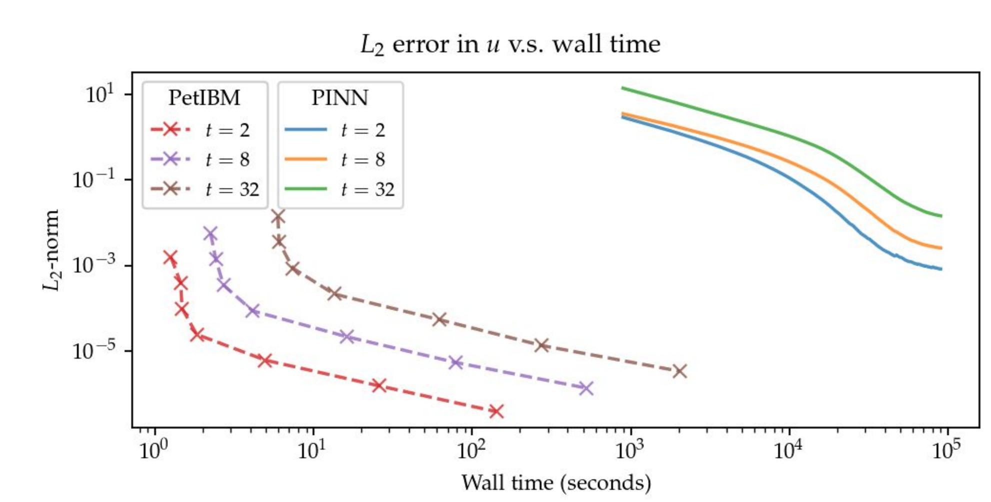


Fig 3. Comparing the cost-performance behaviors against traditional CFD solvers

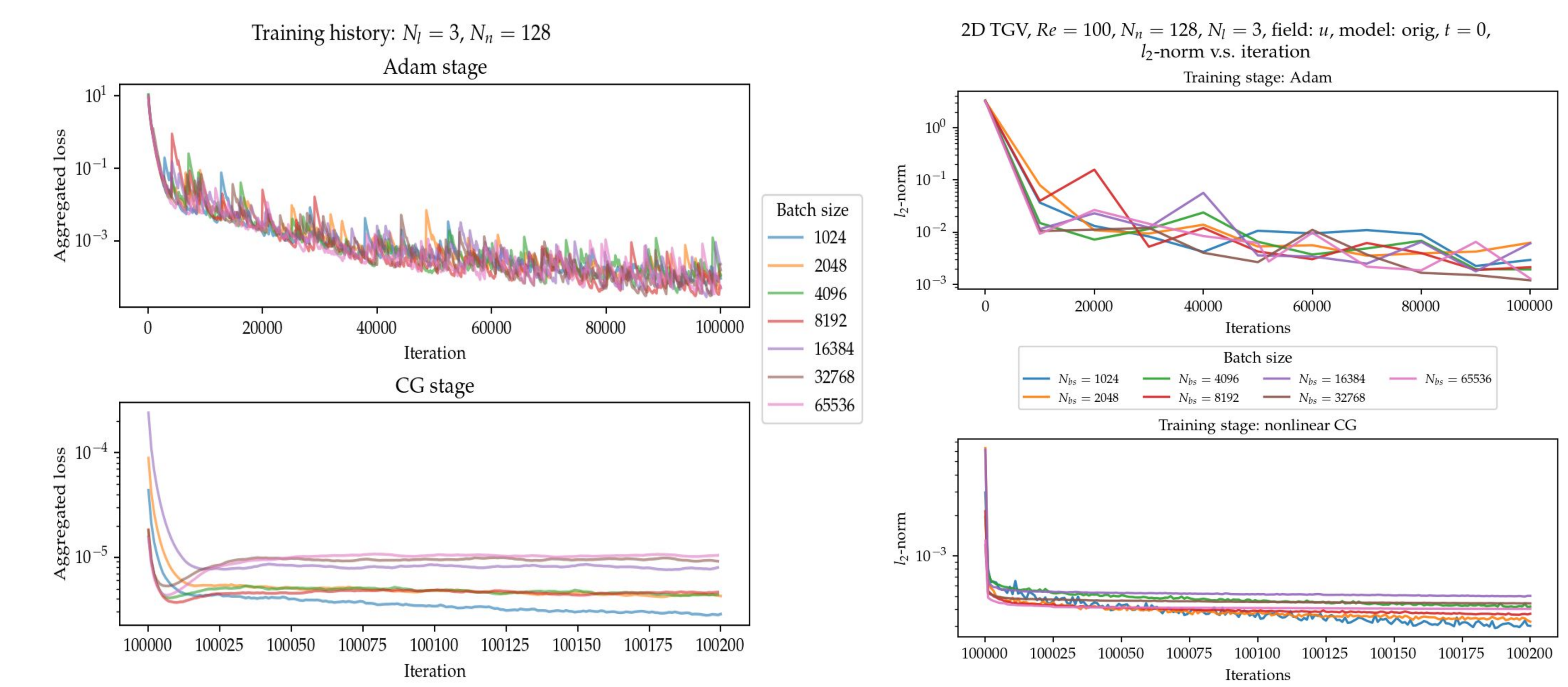


Fig 4. Loss and accuracy versus training iterations show no straightforward relationship

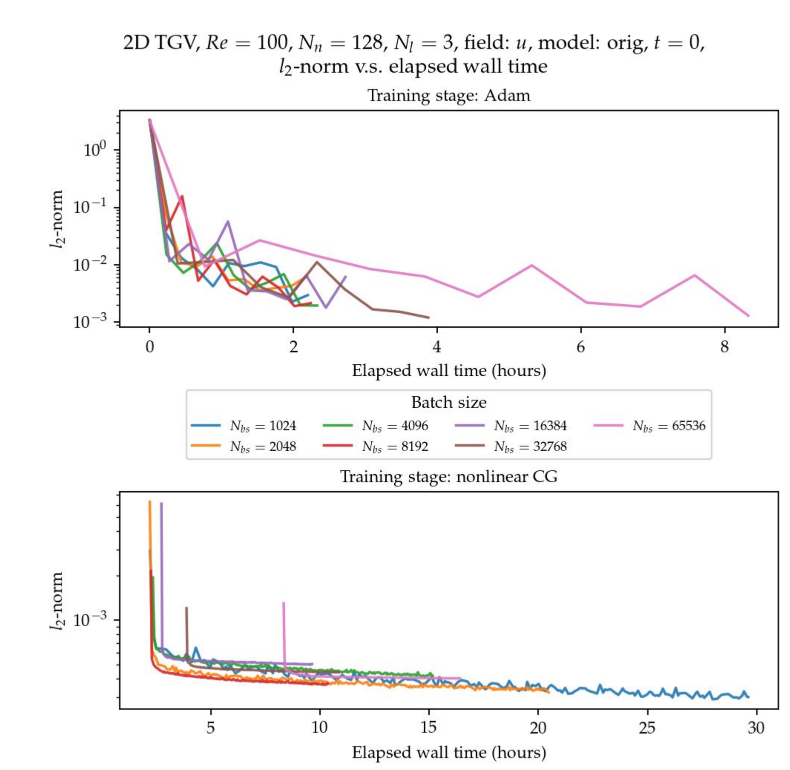
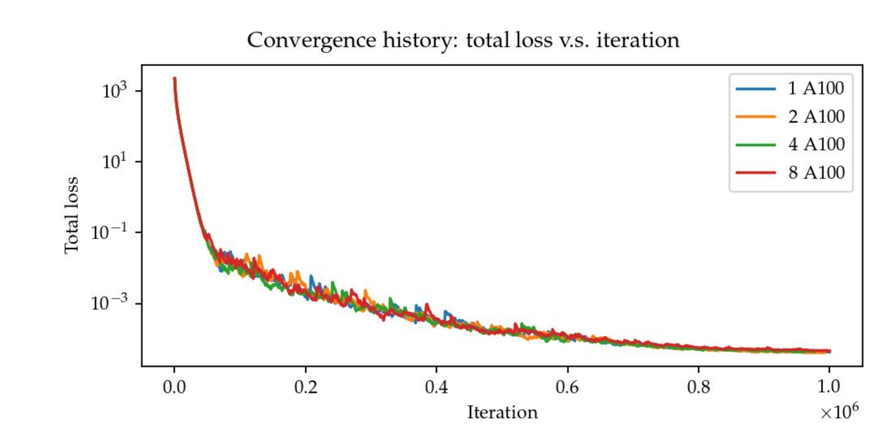


Fig 5. Accuracy versus wall time shows no clear relationship between batch size and time-to-solution



	1 GPUs	2 GPUs	4 GPUs	8 GPUs
Time (sec/1k iters)	85.0	87.7	89.1	90.1
Efficiency (%)	100	97	95	94

Fig 6 and Table 1. Weak-scaling benchmarking. No obvious benefit to convergence.

Vortex Shedding Benchmarking: PINNs Gave Steady-State Solution

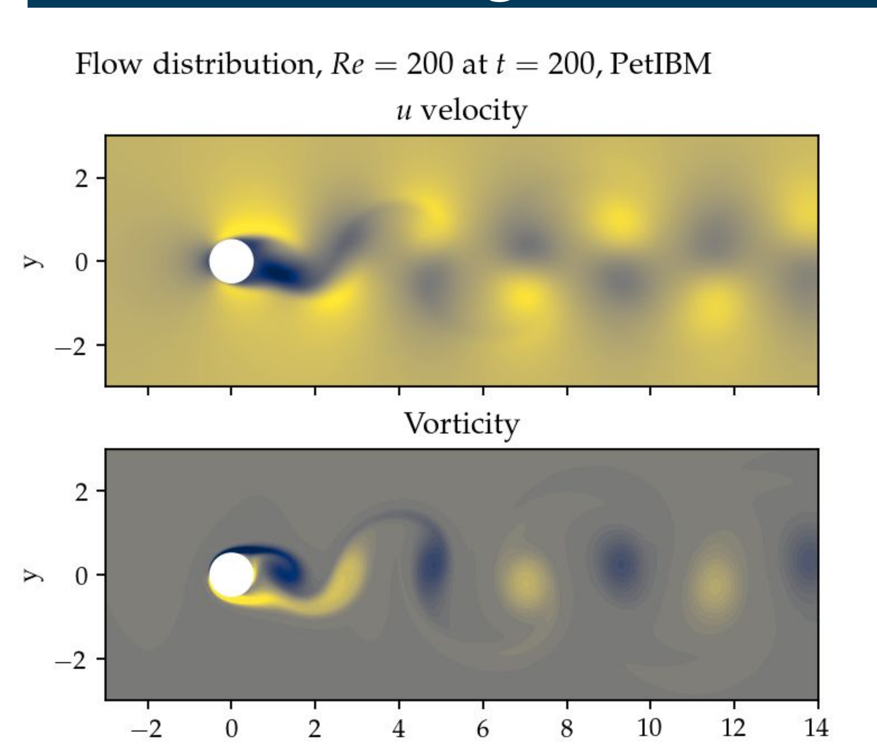


Fig 7. Finite difference solution: flow field is expected to have vortex shedding

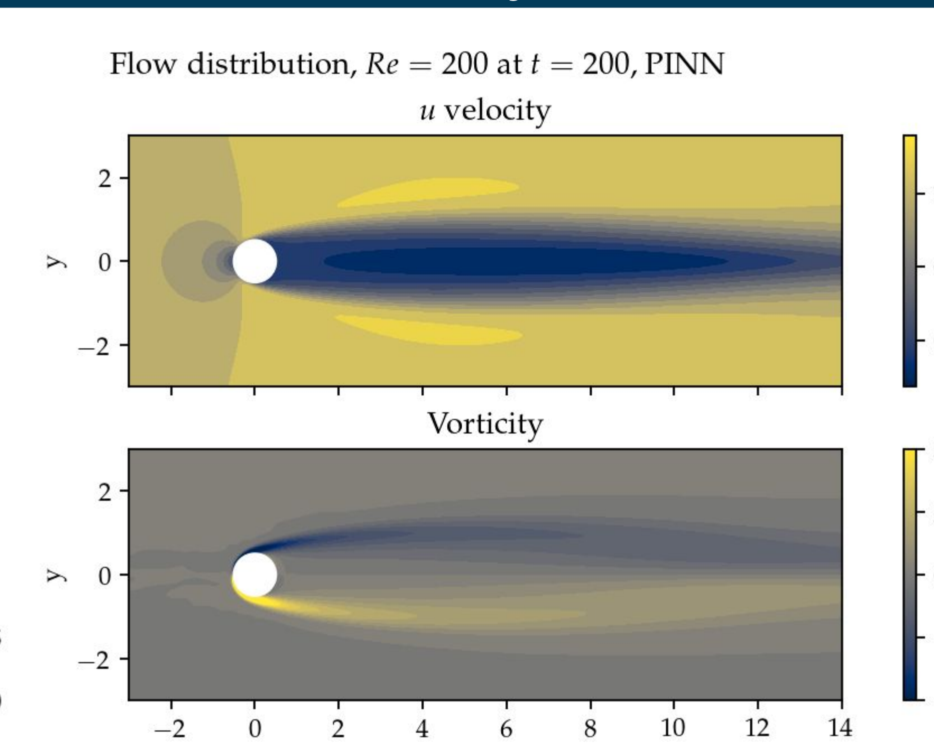


Fig 8. PINNs simulation: no shedding at all

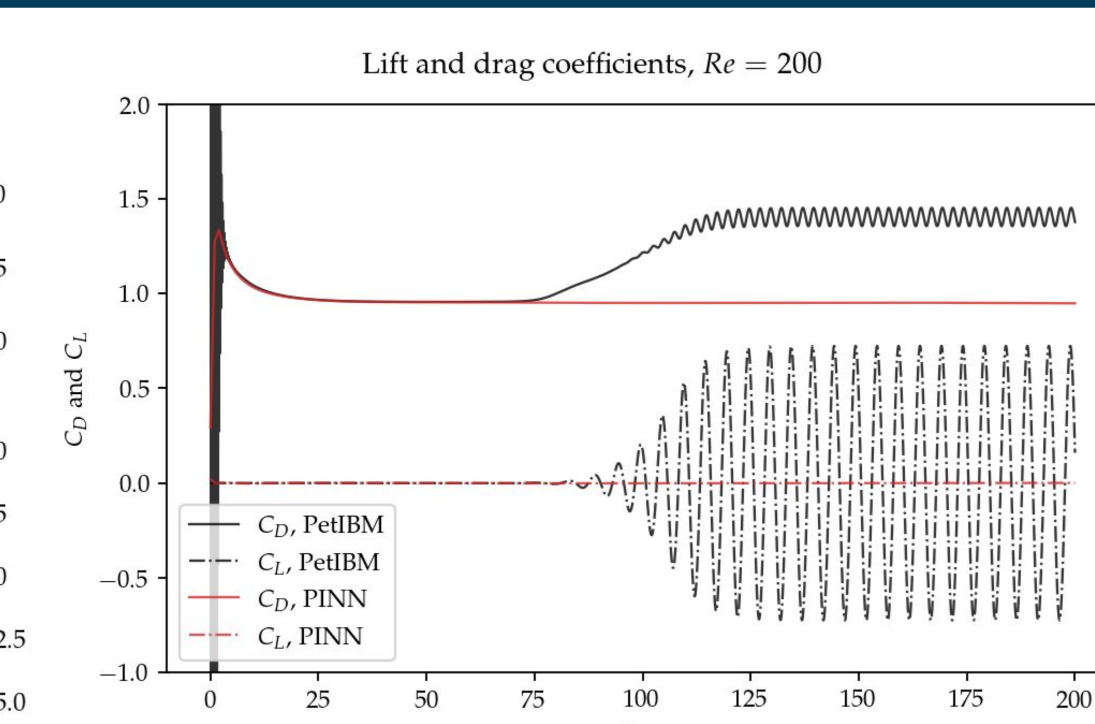


Fig 9. Drag and lift coefficients. PINNs results show a steady-state behavior.