Case 3.4: 2D Laminar Flapping Wing
Case Summary

Per-Olof Persson

Department of Mathematics, University of California, Berkeley
Mathematics Department, Lawrence Berkeley National Laboratory

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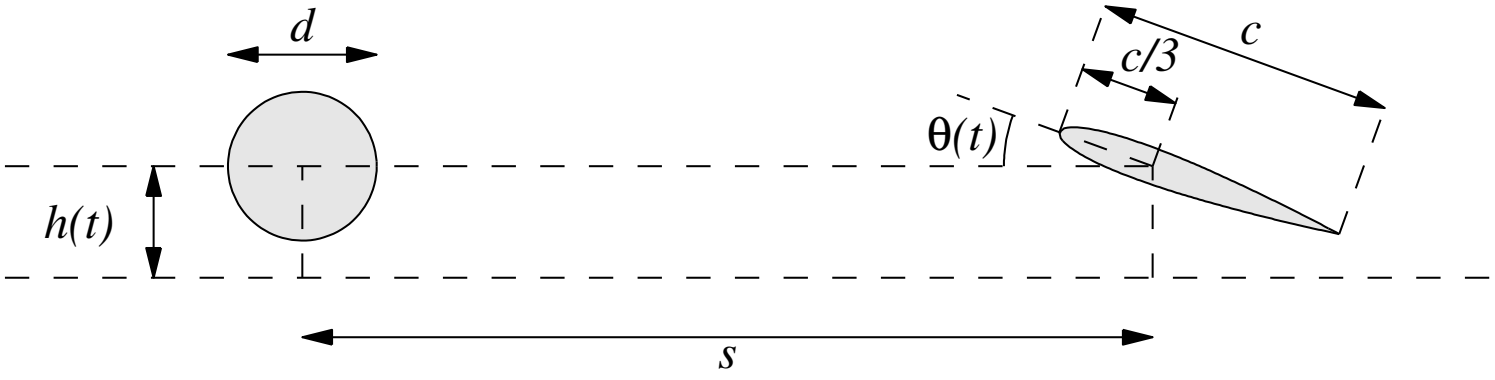
Berkeley Lab

Problem Description

- Inspired by experimental study [Gopalkrishnan/Triantafyllou/et al, '94], computational study in [Persson/Peraire/Bonet '09]
- An oscillating cylinder produces vortices that interact with a heaving and pitching airfoil, in a typical flapping motion
- Freestream Mach = 0.2, Re = 500, St = 0.1 (for cylinder)
- Thrust on airfoil highly dependent on distance s and the vortices convected from cylinder – potentially good case for high-order methods

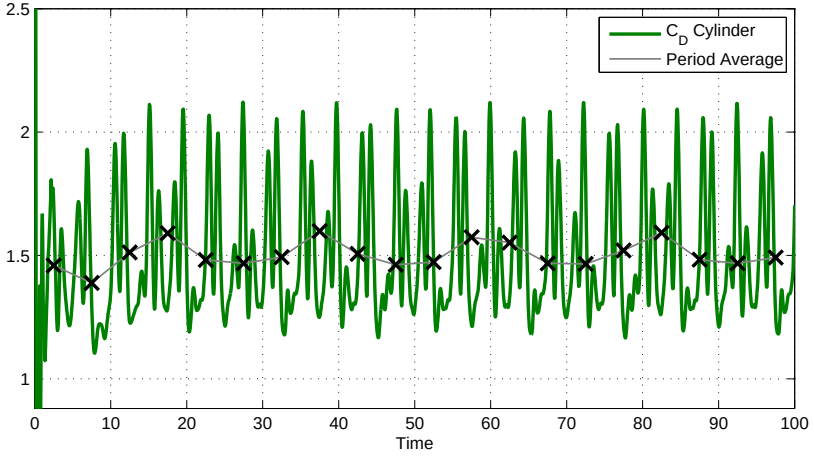


Contributing Groups

- UC Berkeley [Persson]
  - DG, explicit RK, triangular meshes
- UMich [Kast/Fidkowski]
  - DG, explicit RK, triangular meshes
- GWU [Wang/Liang]
  - SD, explicit RK, quadrilateral meshes
- A direct comparison between the results difficult because of:
  - Irregular behavior of the period-averages for the St = 0.1 case
  - Some differences in initial solution
- However, qualitatively we can compare the time-evolution of the forces and the period averages
- Consider case $s = 3.5$ only since no significant differences

Time evolutions, cylinder C_D

UC Berkeley:



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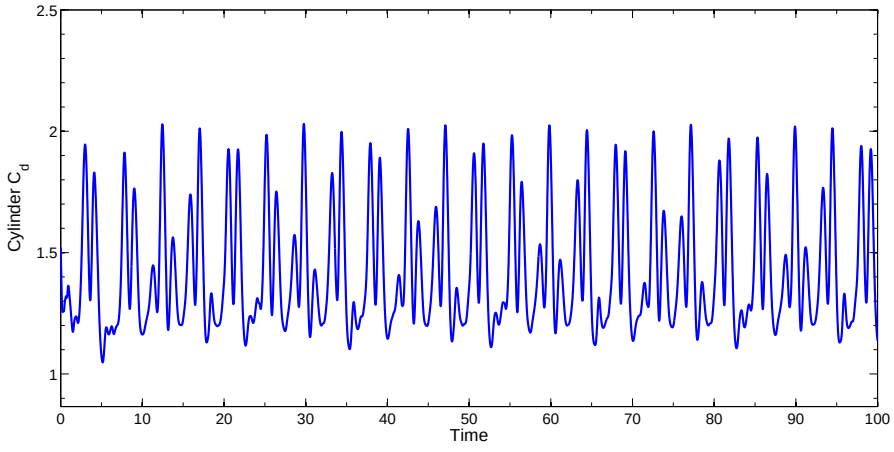
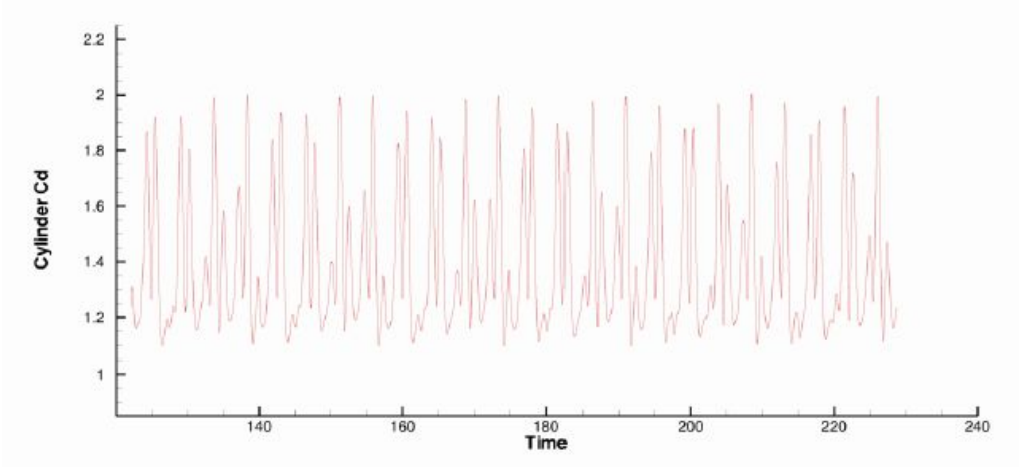


Note:

- Different initial condition in UMich
- Different x-axis in GWU
- However, visually good agreement

GWU:



Time evolutions, cylinder C_L

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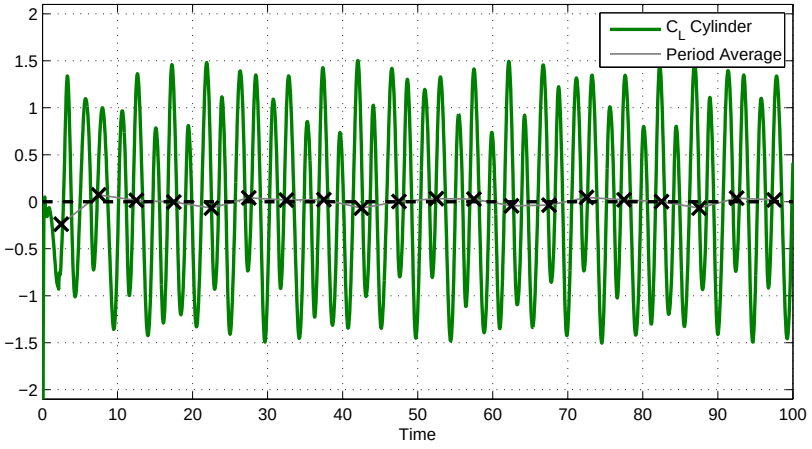

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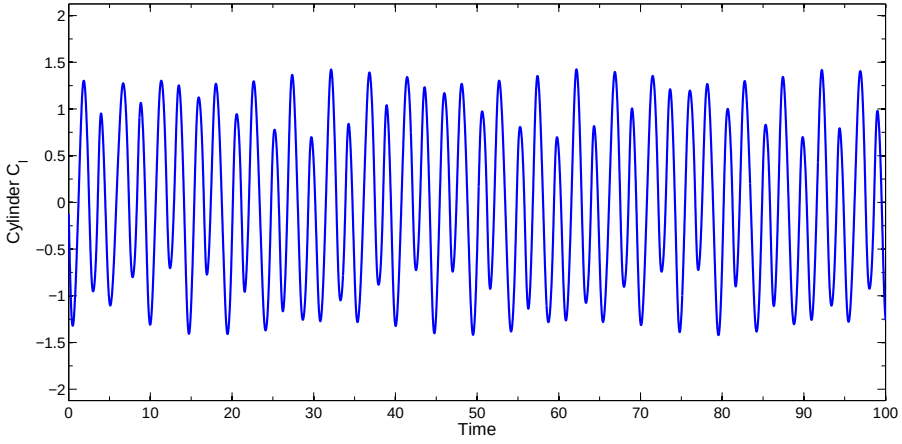

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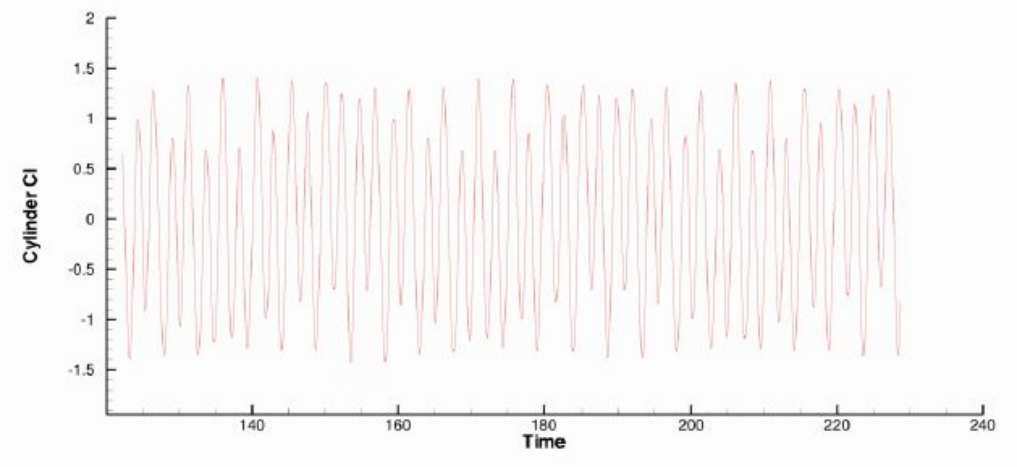

Time evolutions, airfoil C_D

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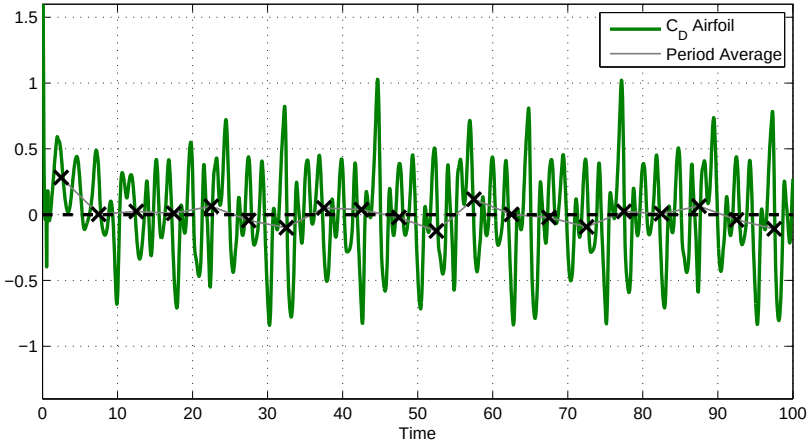

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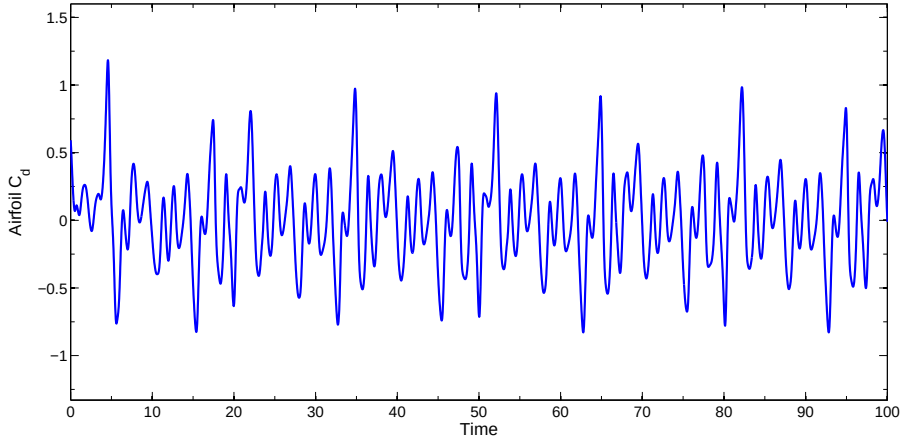

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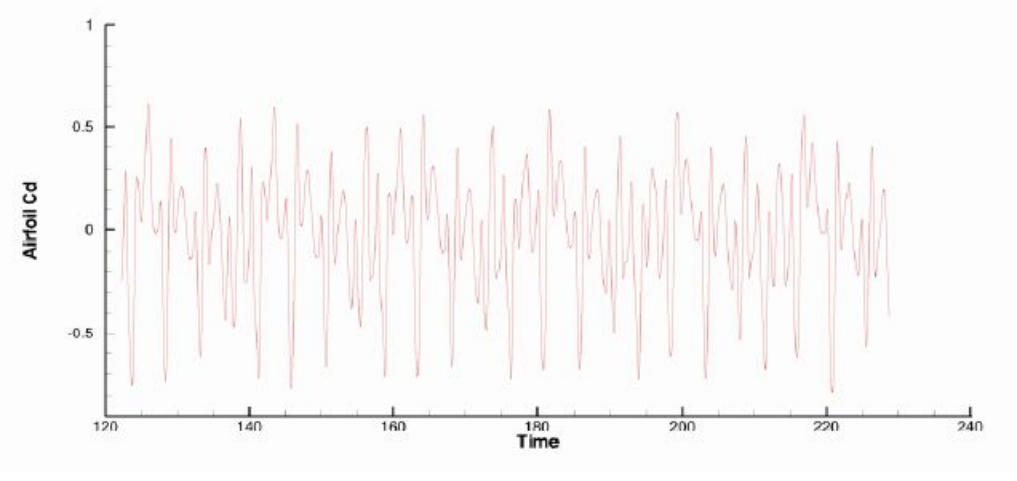

Time evolutions, airfoil C_L

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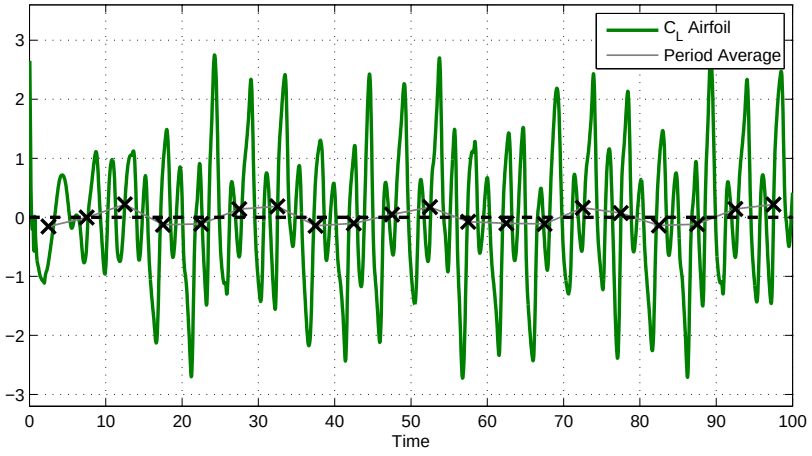

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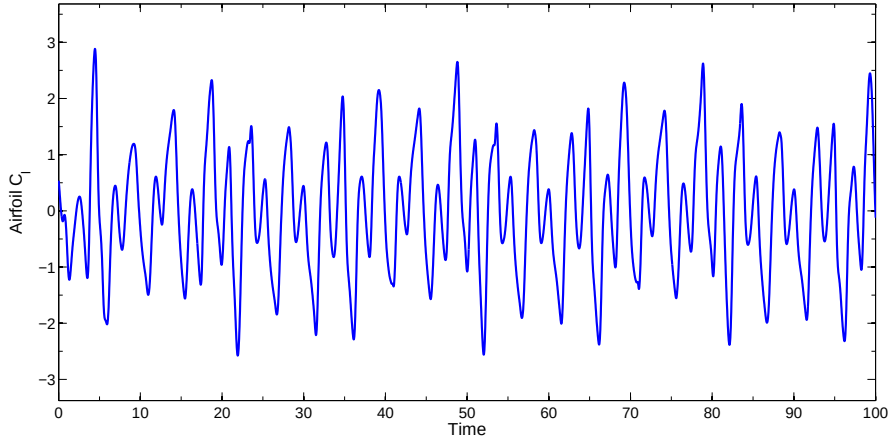

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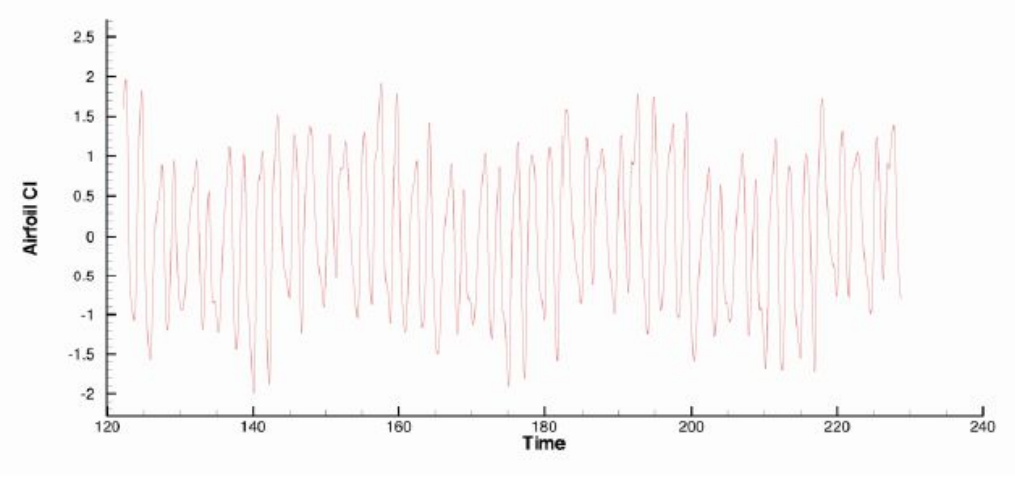
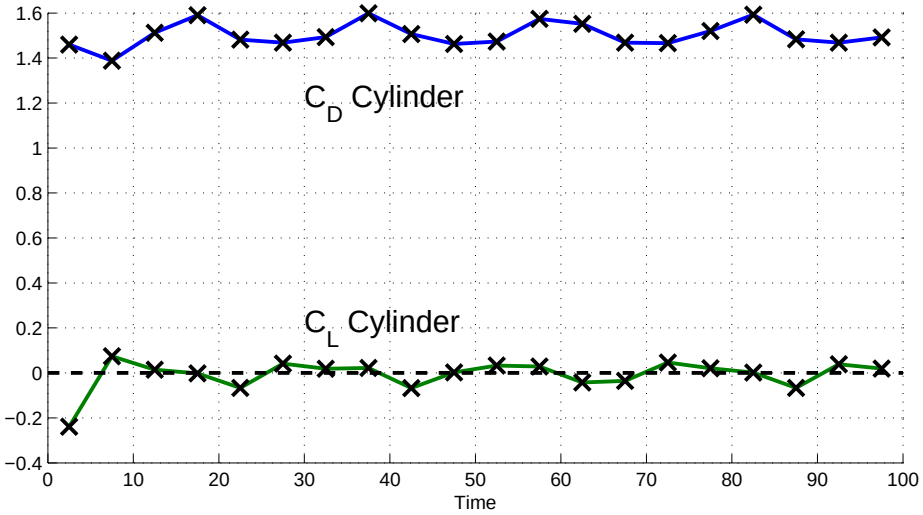


Period averages, cylinder

UC Berkeley:



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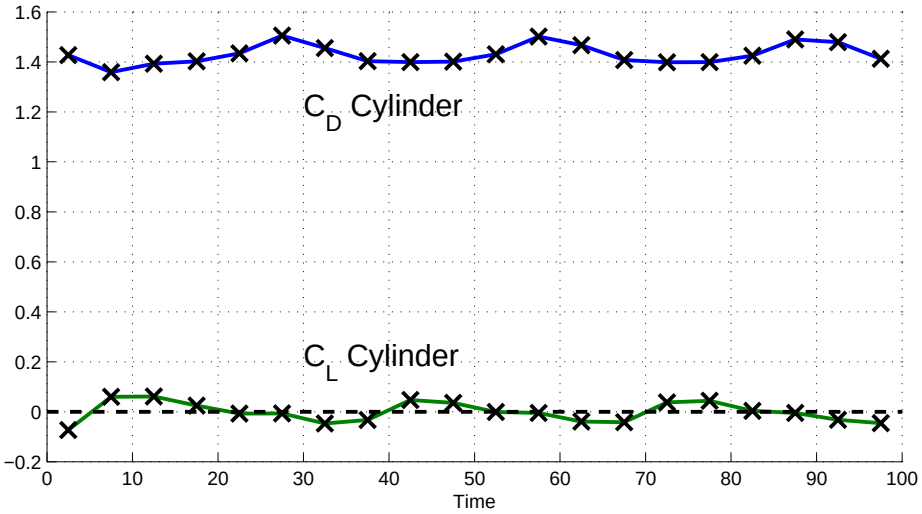

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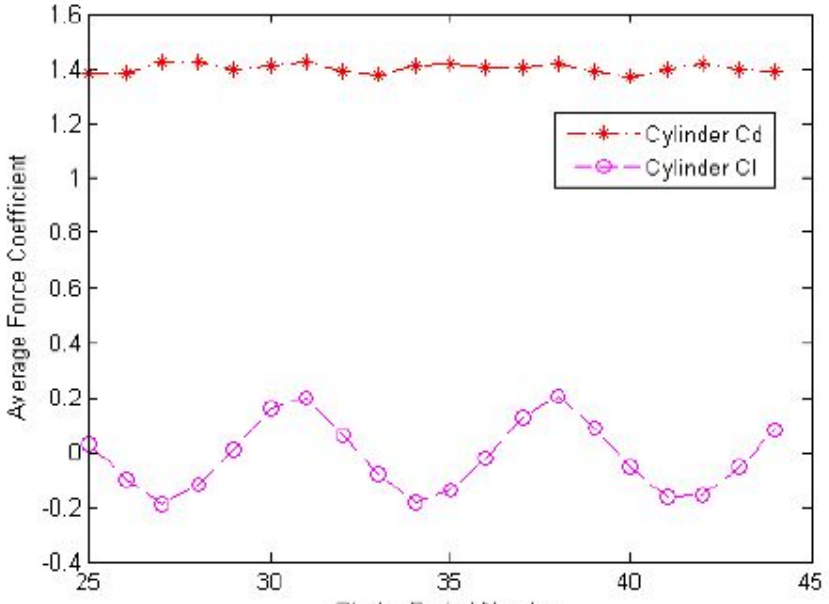

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Period averages, airfoil

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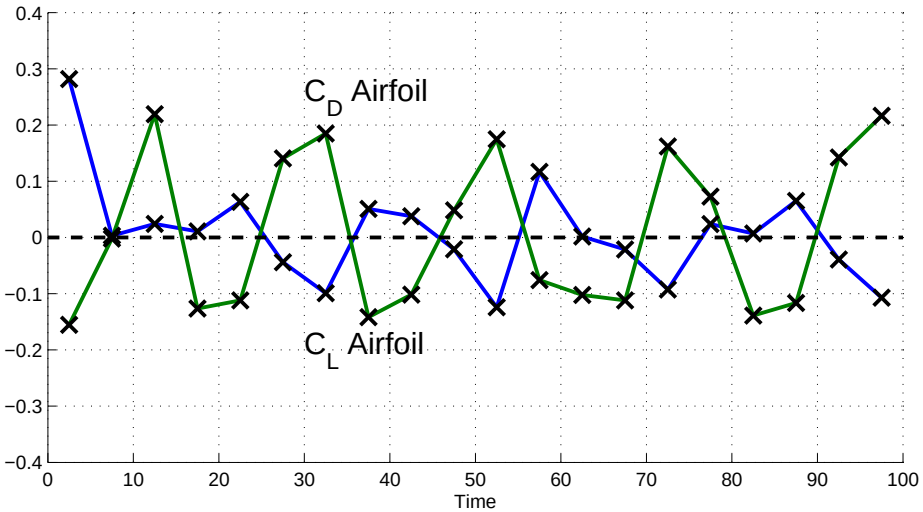

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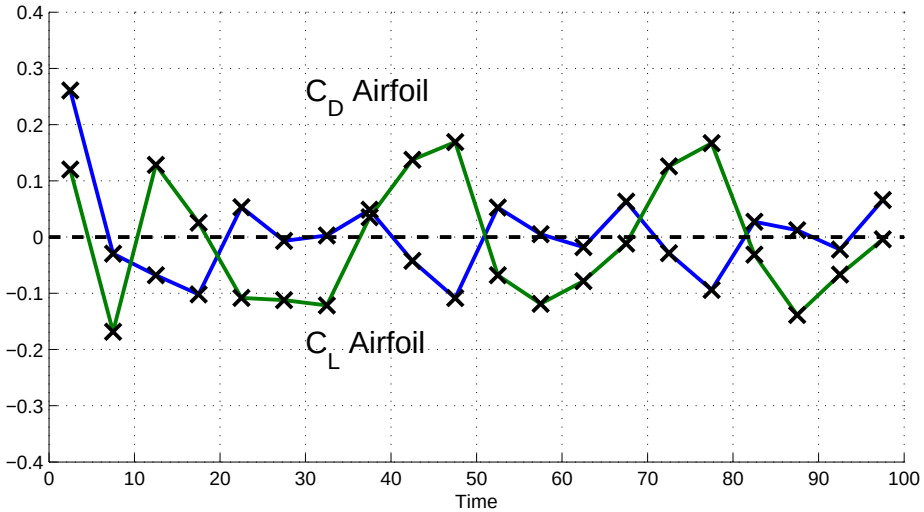

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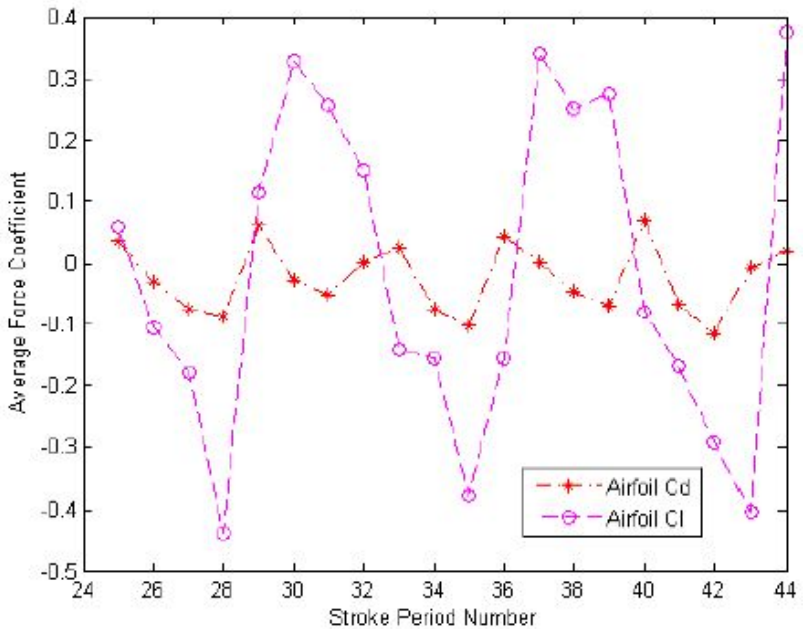

Summary

- The current Strouhal number makes it hard to compare period-averaged quantities
- However, the results appear consistent
- The p-convergence by UCB and UMich indicate fully converged solutions
- Comparisons between polynomial degrees p indicate large benefits with high-order discretizations
- Future improvements:
  - Use parameters that converge to time-periodic solutions
  - Possibly: Calculate *exact* periodic solutions (hard)
  - More rigorous comparison of computational cost