Test case C1.2: Ringleb flow Summary

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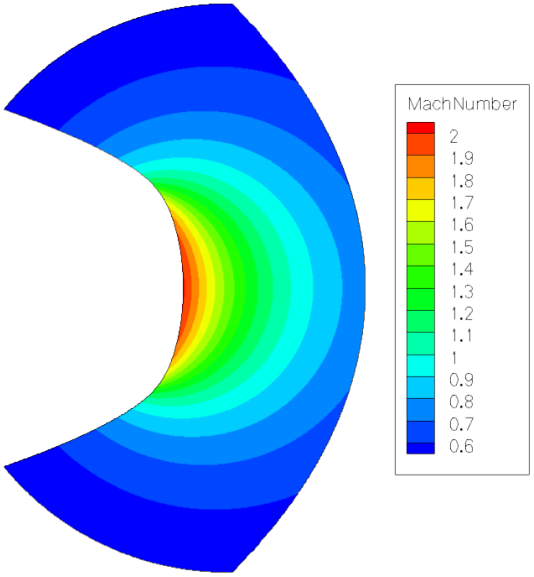

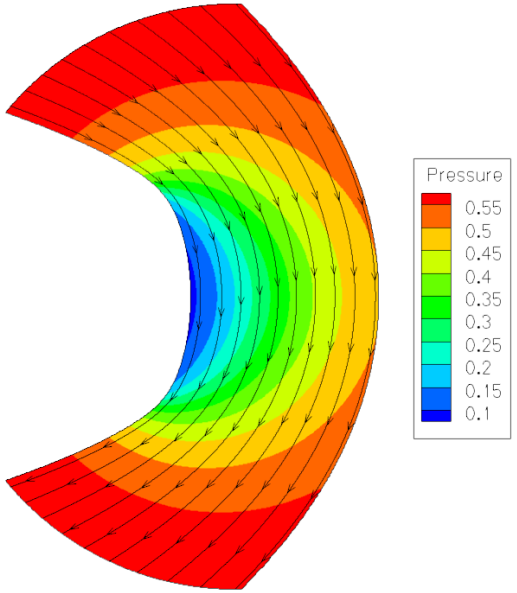

2nd International Workshop on High Order CFD Methods
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Contributions

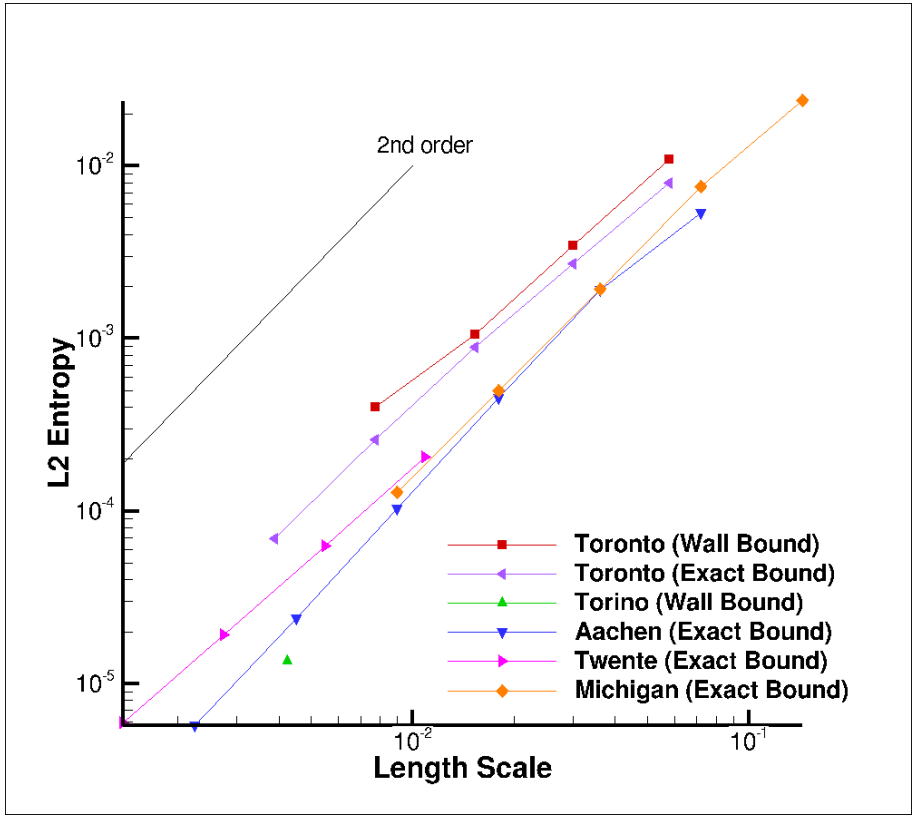
- University of Toronto
  - SBP/SAT FD, Newton-Krylov
- Politecnico Torino
  - DG, explicit Runge Kutta
- RWTH Aachen
  - DG, Newton-Krylov
- University of Twente / University of Bergen
  - SBP/SAT FD, Newton-Krylov
- University of Michigan
  - DG, Newton-Krylov
  - Adaption

Observations

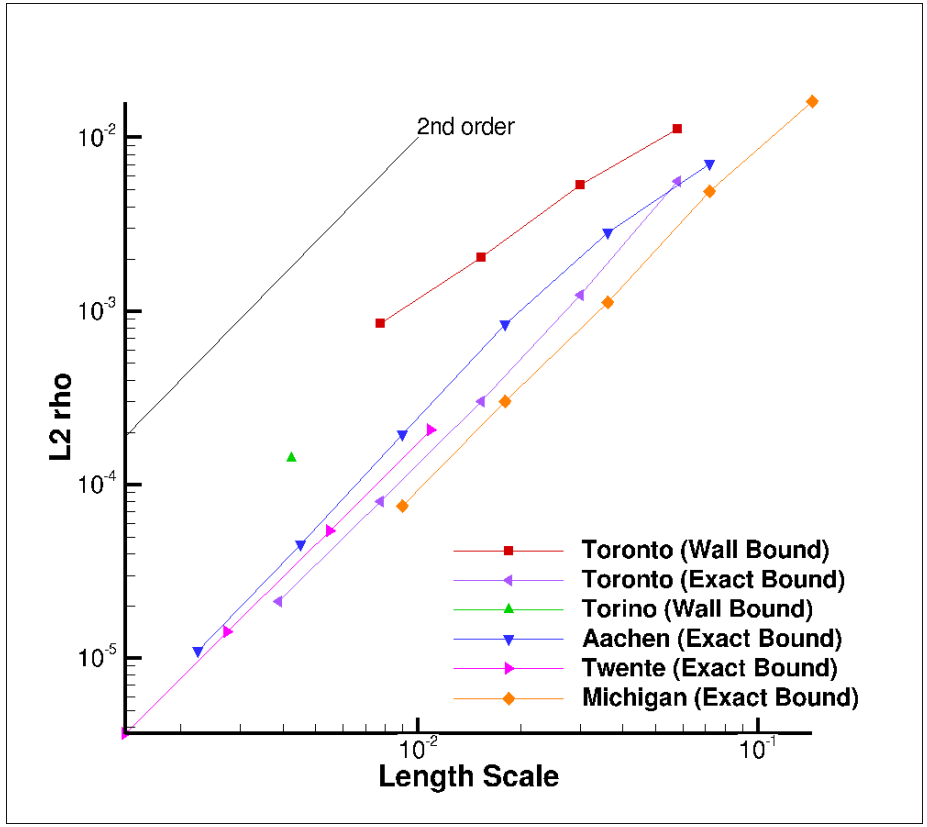
- Correct representation of the wall is crucial
  - 2nd order FD schemes fail with standard metric
    - Solutions, FD
      - Penalize against exact solution (Twente, Toronto)
      - Use higher order representation (Toronto)
    - Solutions, DG
      - Use exact solution (Aachen, Michigan)
      - Use relatively fine grids (Torino)
- Newton-Krylov most popular iterative solver

Accuracy, p = 1 (2^{nd} order)

Entropy

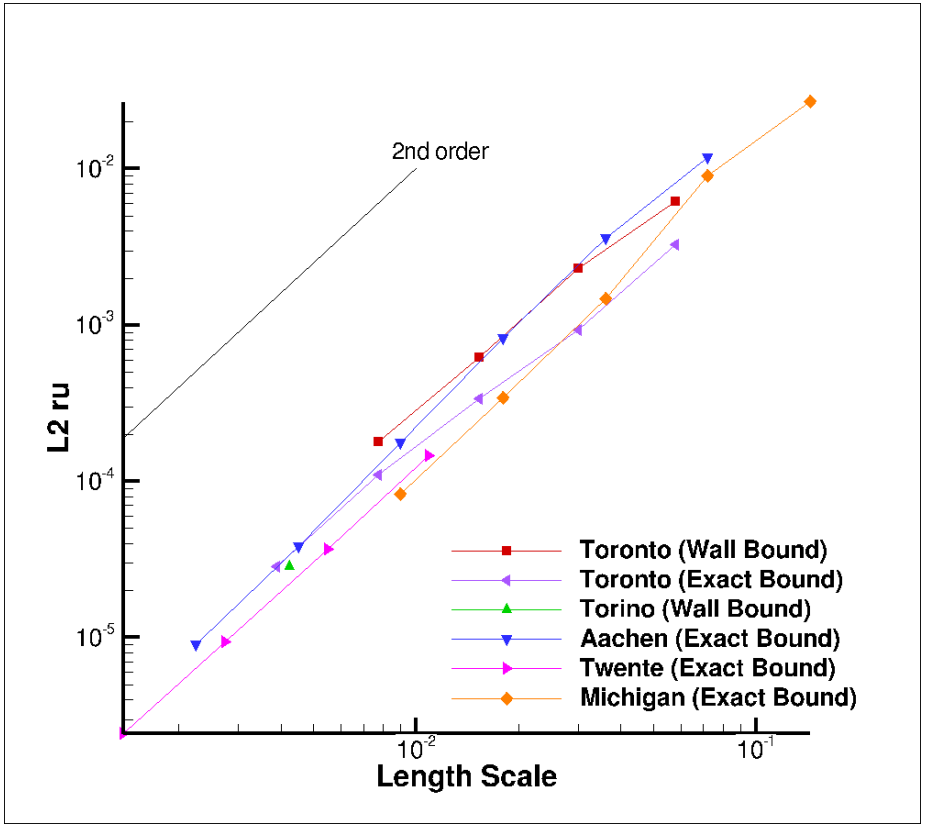


Density

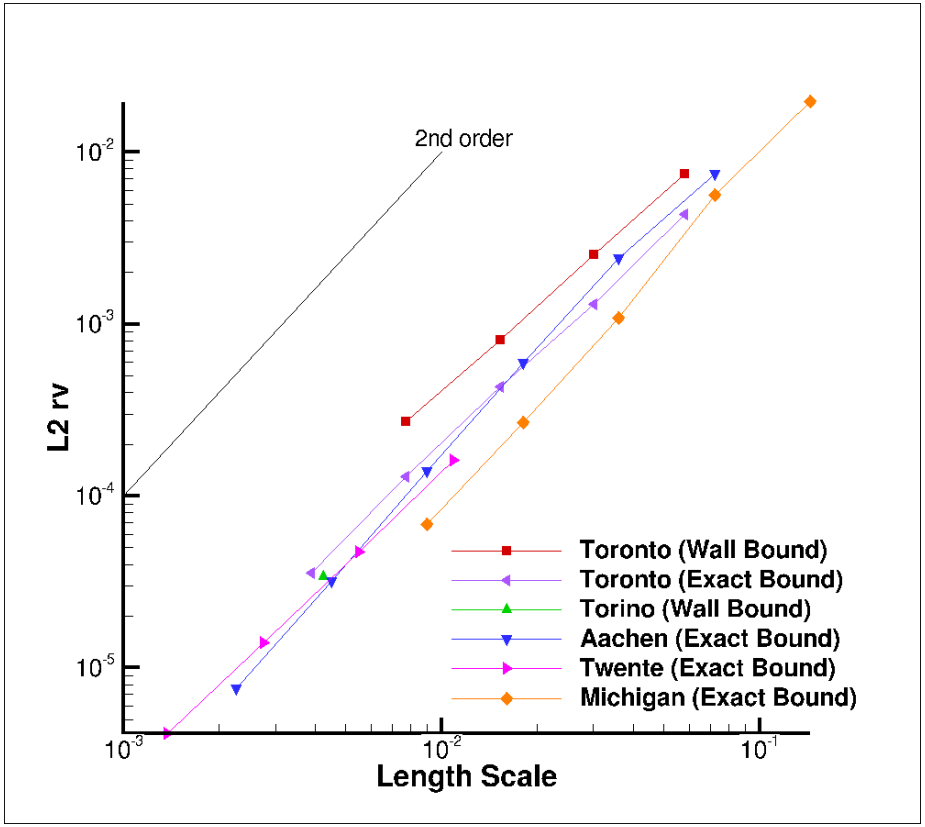


Accuracy, p = 1 (2nd order)

X-Momentum

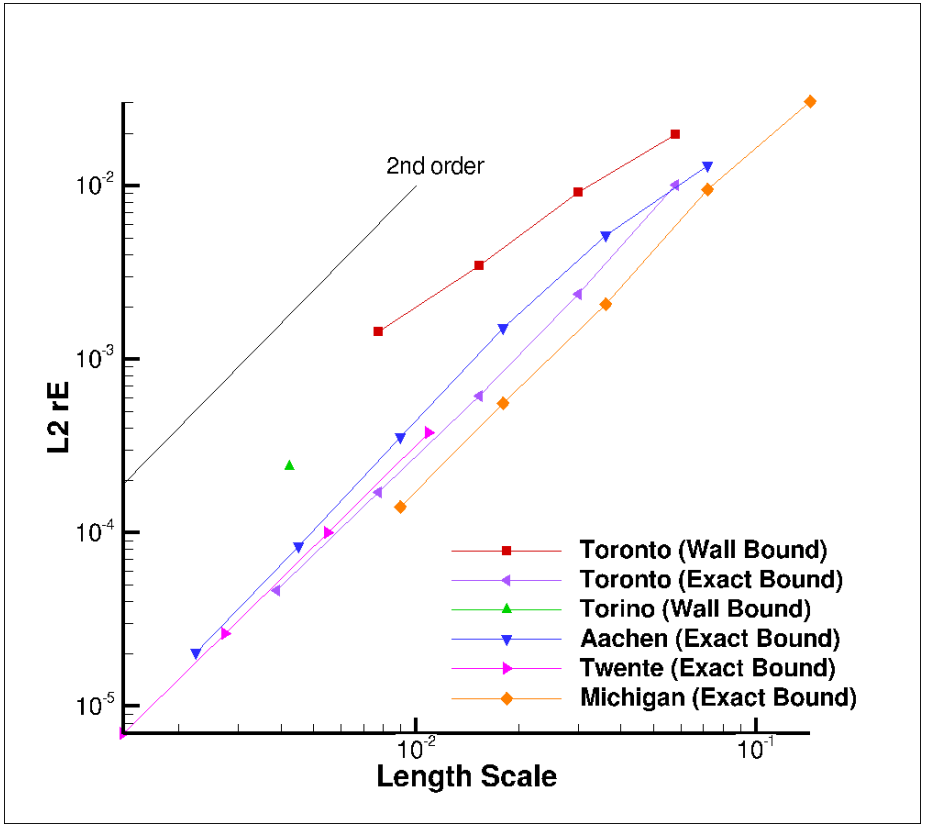


Y-Momentum



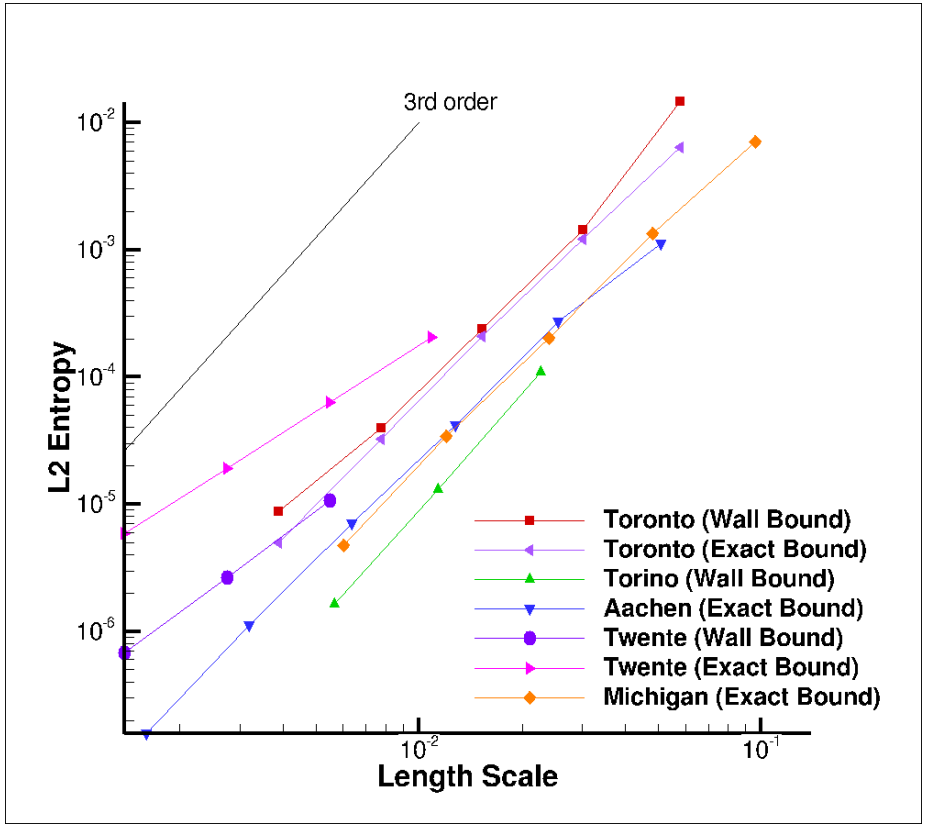
Accuracy, p = 1 (2^{nd} order)

Energy

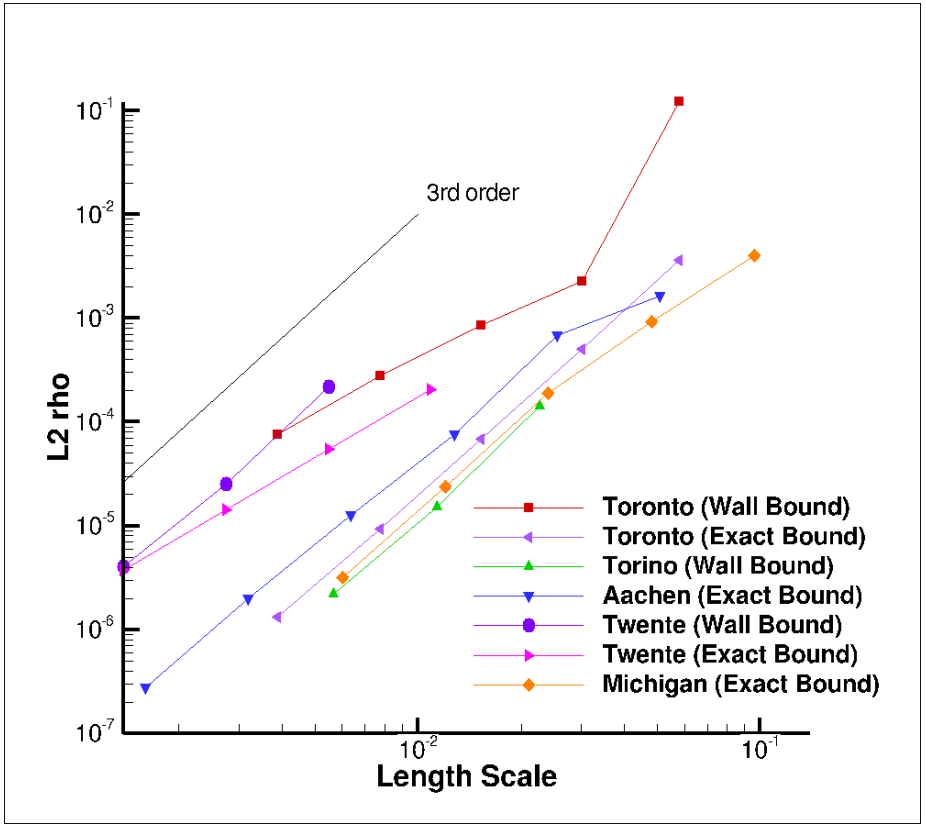


Accuracy, p = 2 (3rd order)

Entropy

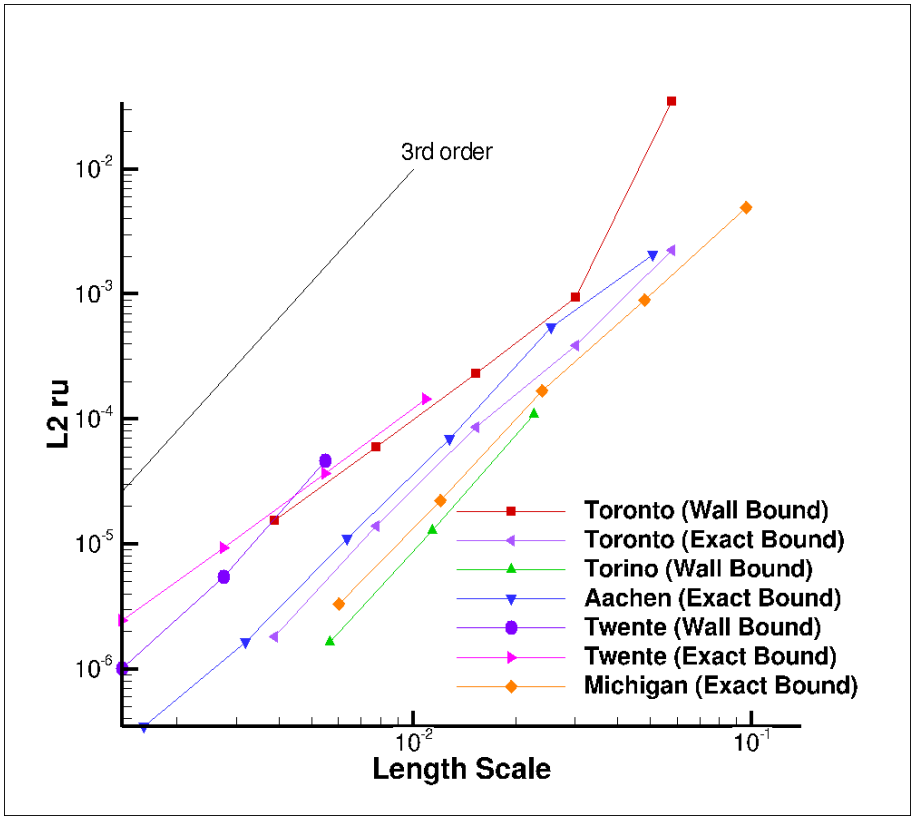


Density

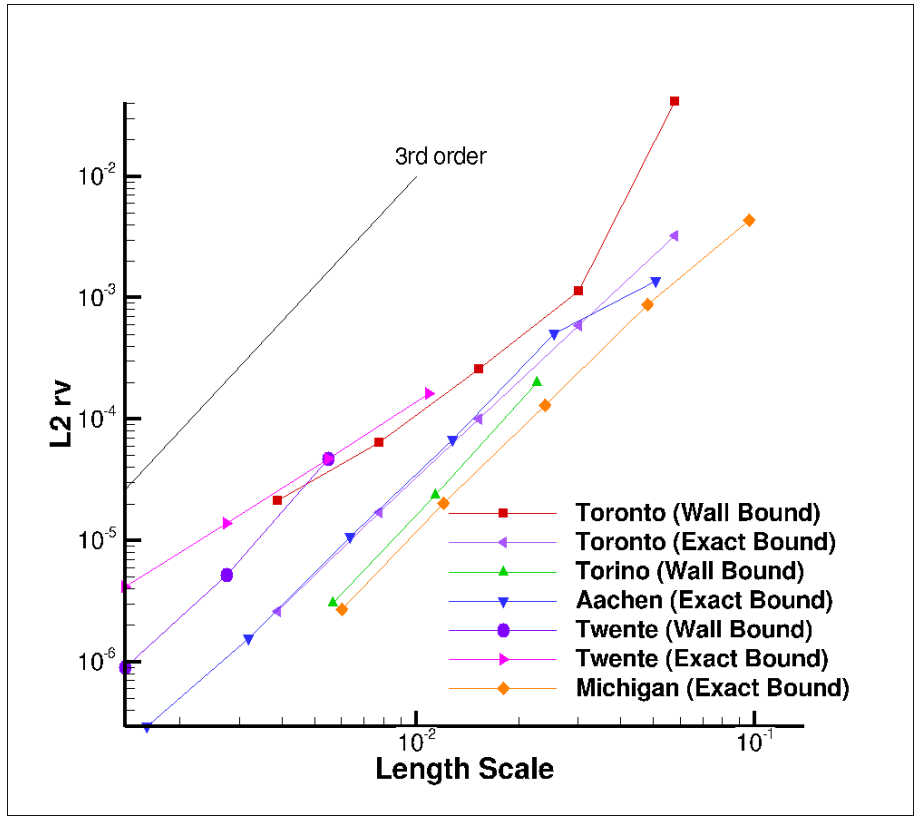


Accuracy, p = 2 (3rd order)

X-Momentum

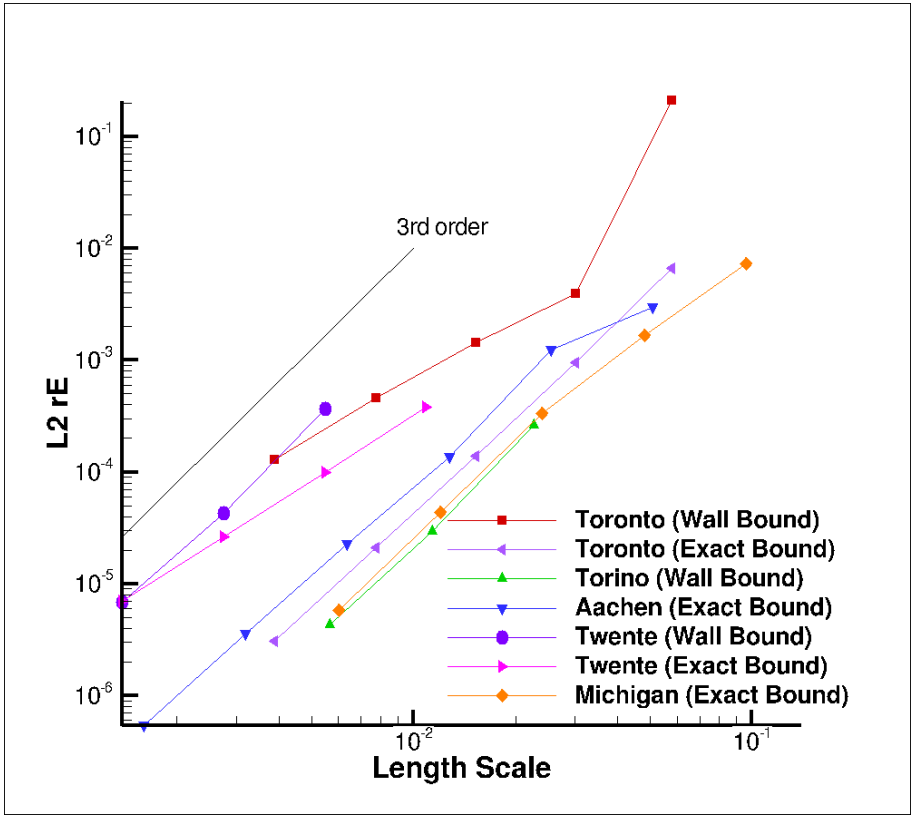


Y-Momentum



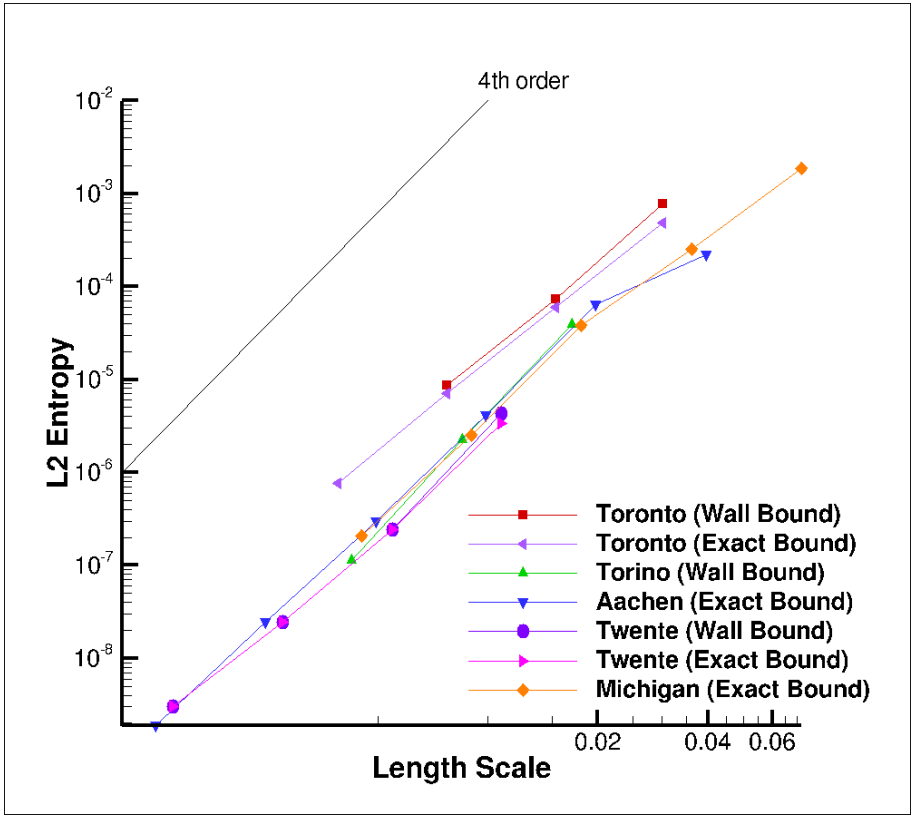
Accuracy, p = 2 (3rd order)

Energy

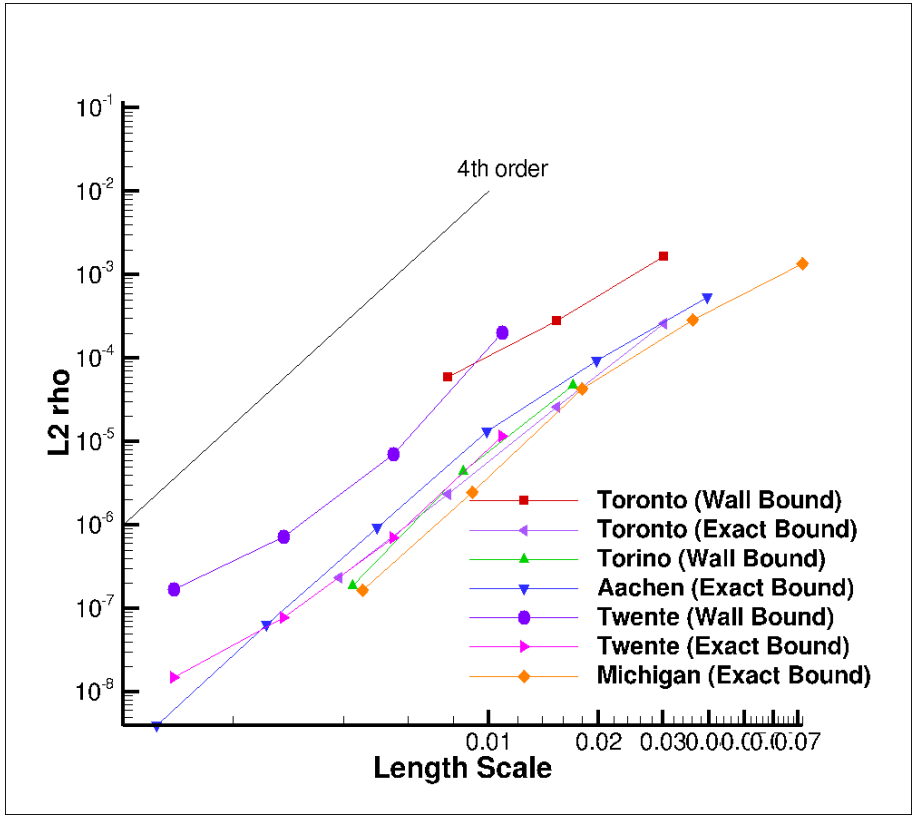


Accuracy, p = 3 (4th order)

Entropy

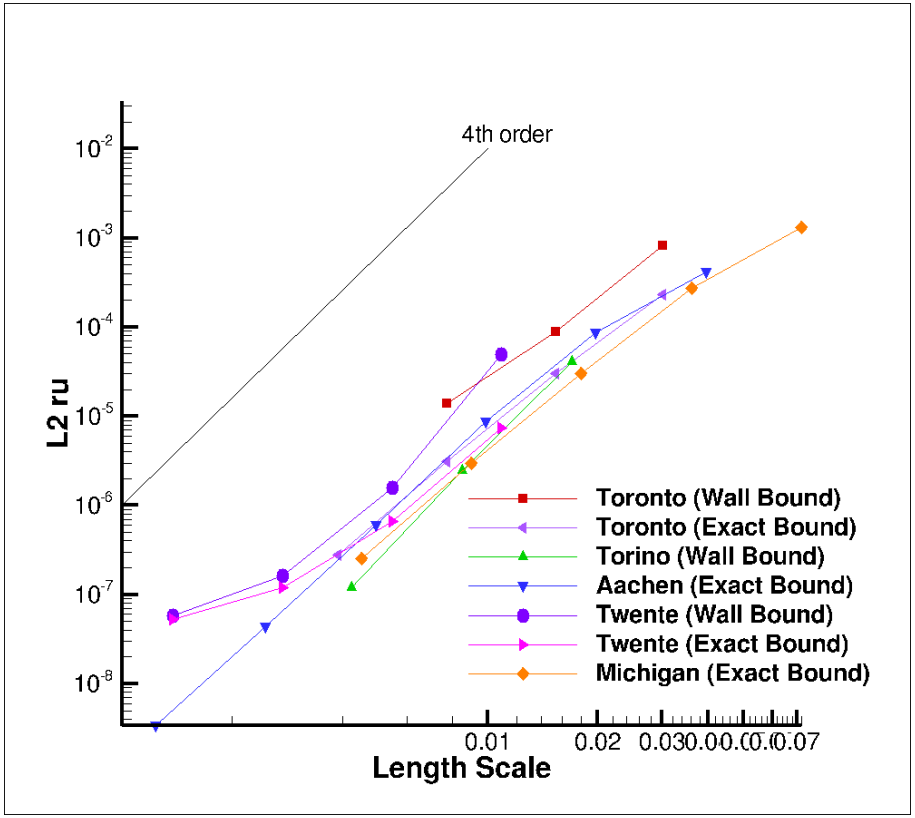


Density

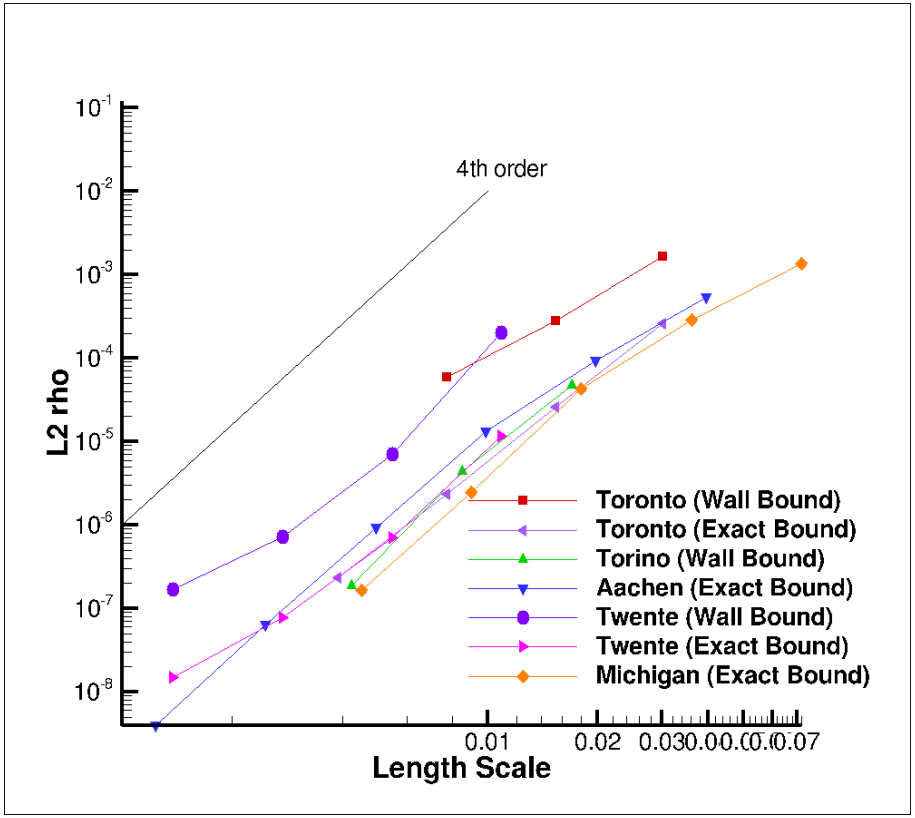


Accuracy, p = 3 (4th order)

X-Momentum

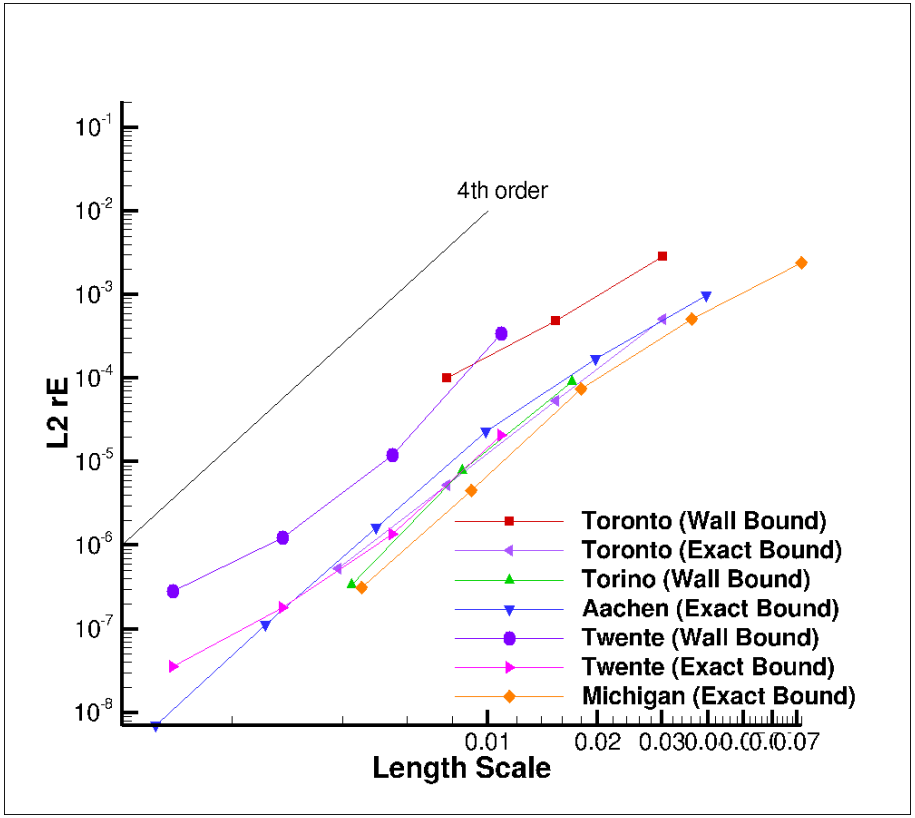


Y-Momentum



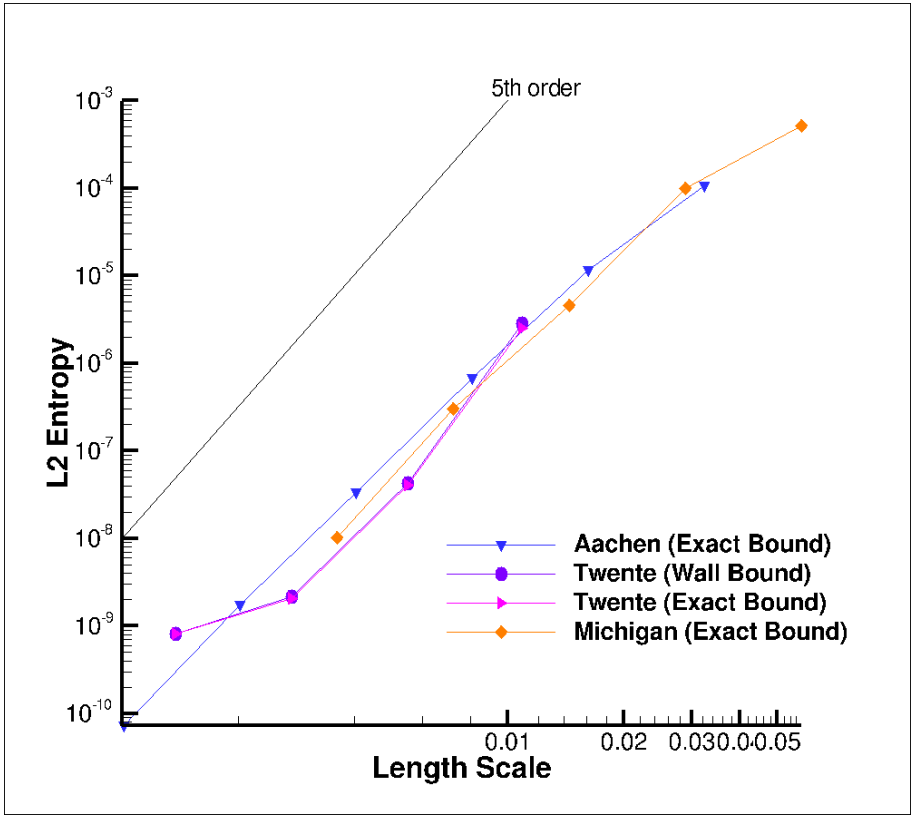
Accuracy, p = 3 (4th order)

Energy

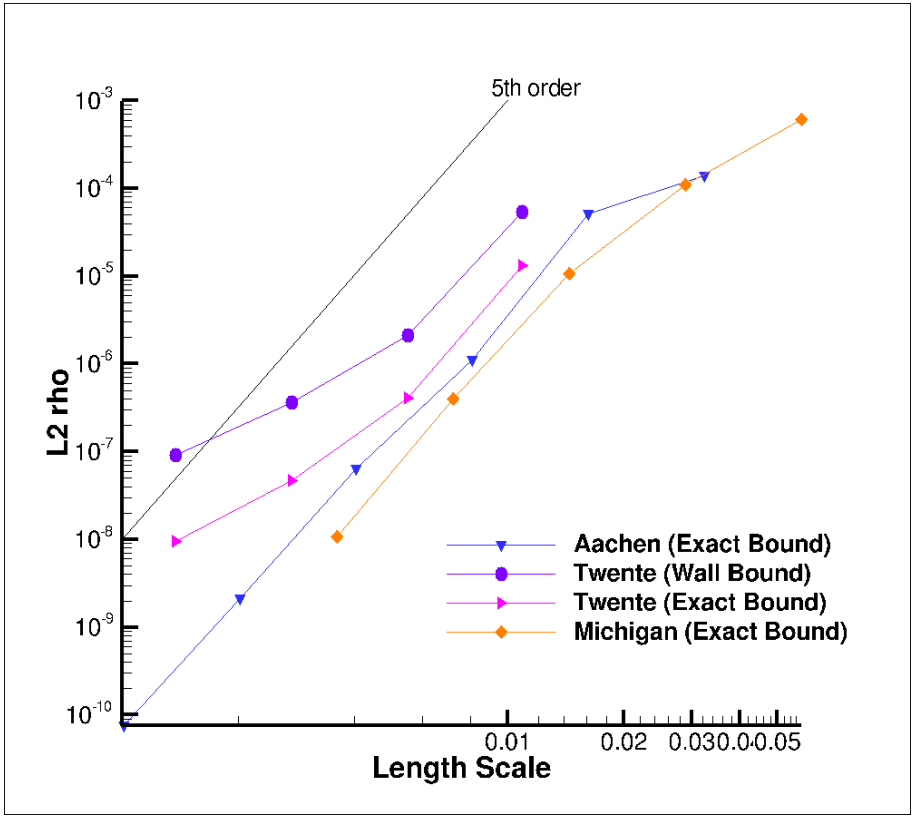


Accuracy, p = 4 (5^{th} order)

Entropy

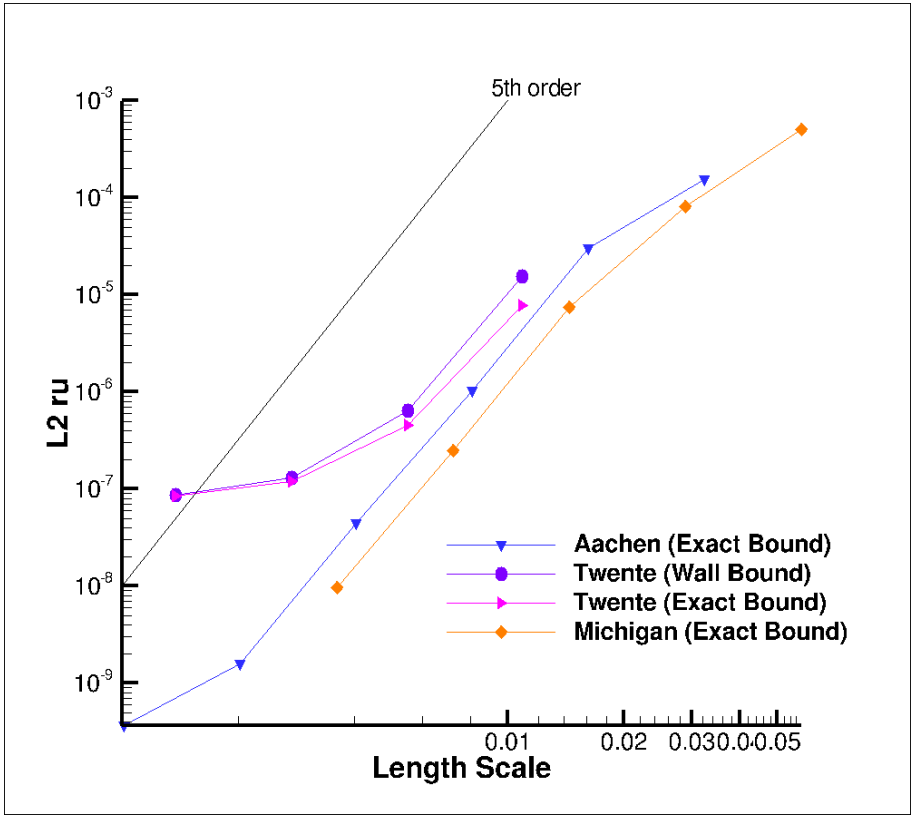


Density

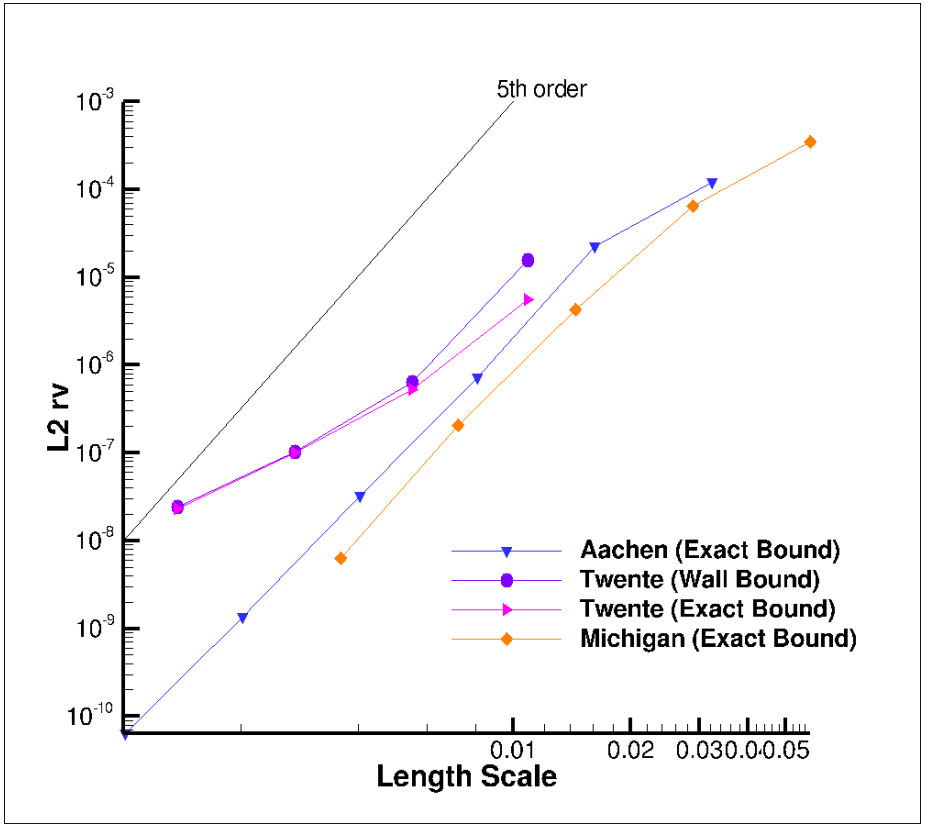


Accuracy, p = 4 (5th order)

X-Momentum

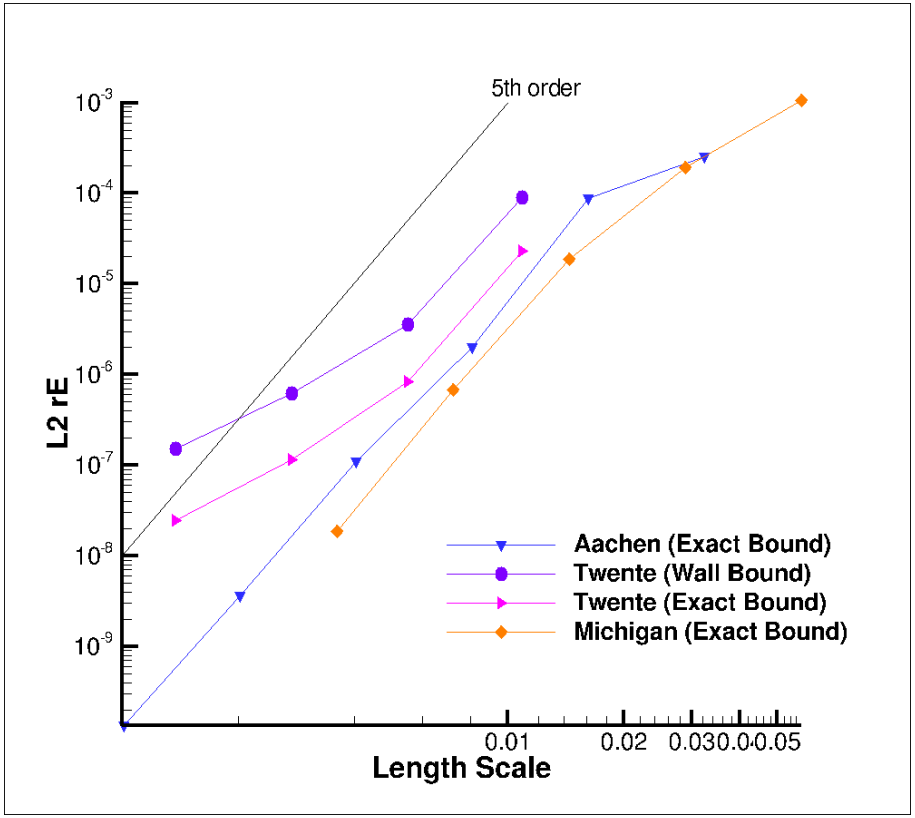


Y-Momentum



Accuracy, p = 4 (5th order)

Energy

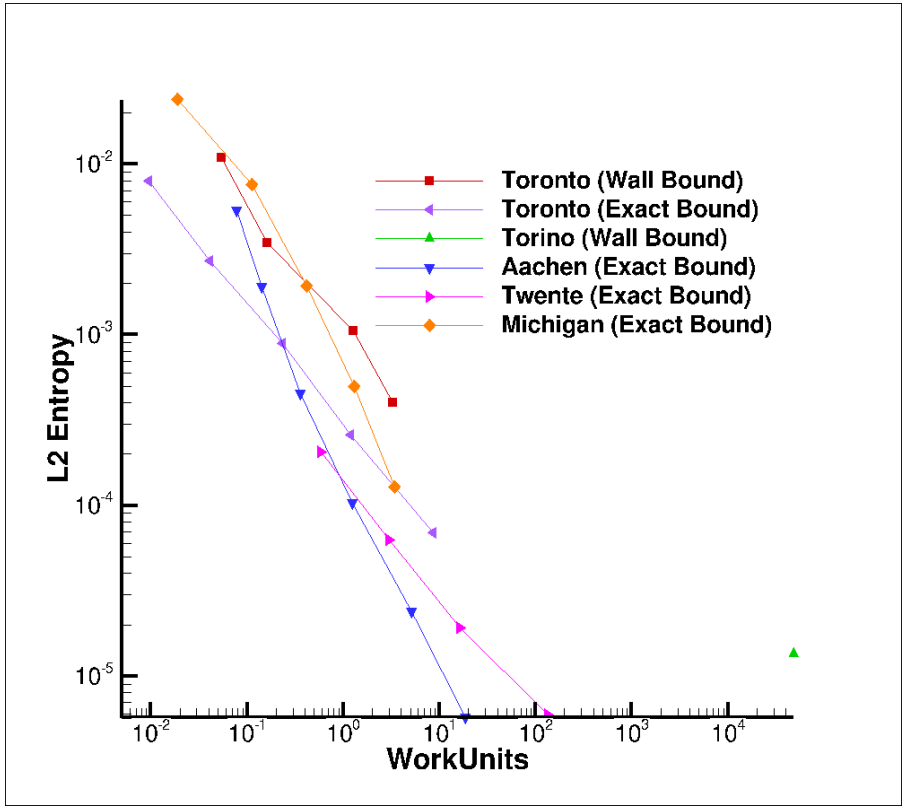


Efficiency

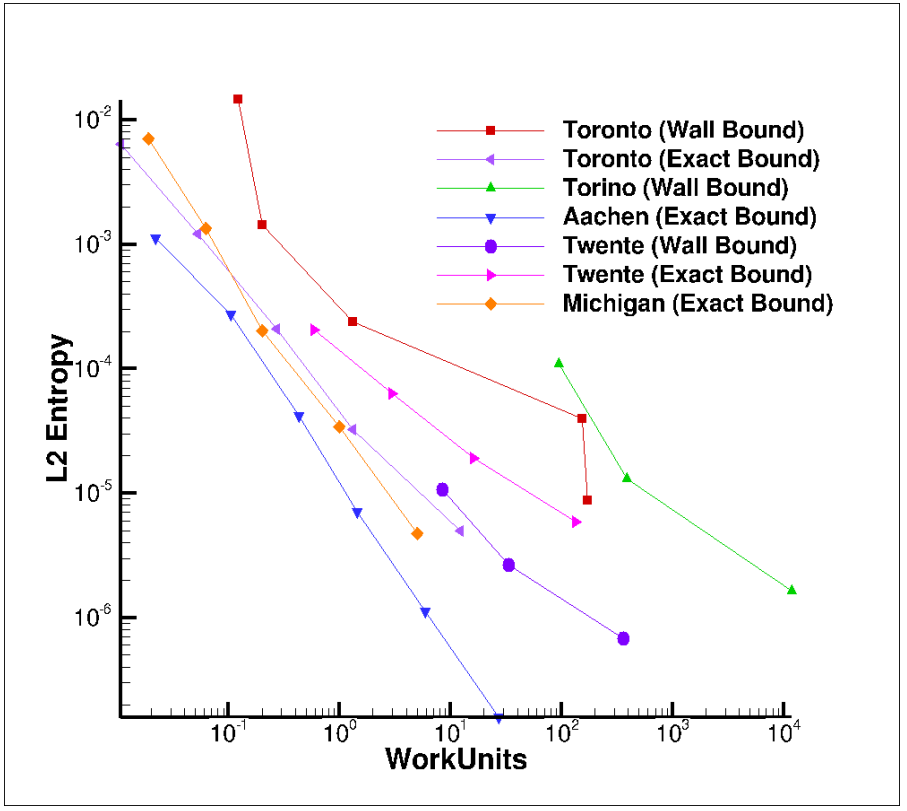
- All codes are research codes
  - Most likely not fully optimized. Could easily be a factor of 2
- Which boundary conditions are used
  - Inviscid walls vs. exact solution can make a big difference
- Initial solution is exact solution
  - Finer grids and/or high order schemes are close => Efficiency cannot be fairly compared
- Memory usage not taken into account
  - Newton Krylov uses a lot of memory
    - Not a problem in 2D, but possibly in 3D
- Most efficient algorithm seems Newton Krylov
  - Preconditioned GMRES as iterative solver

Efficiency, entropy error

p = 1, 2nd order

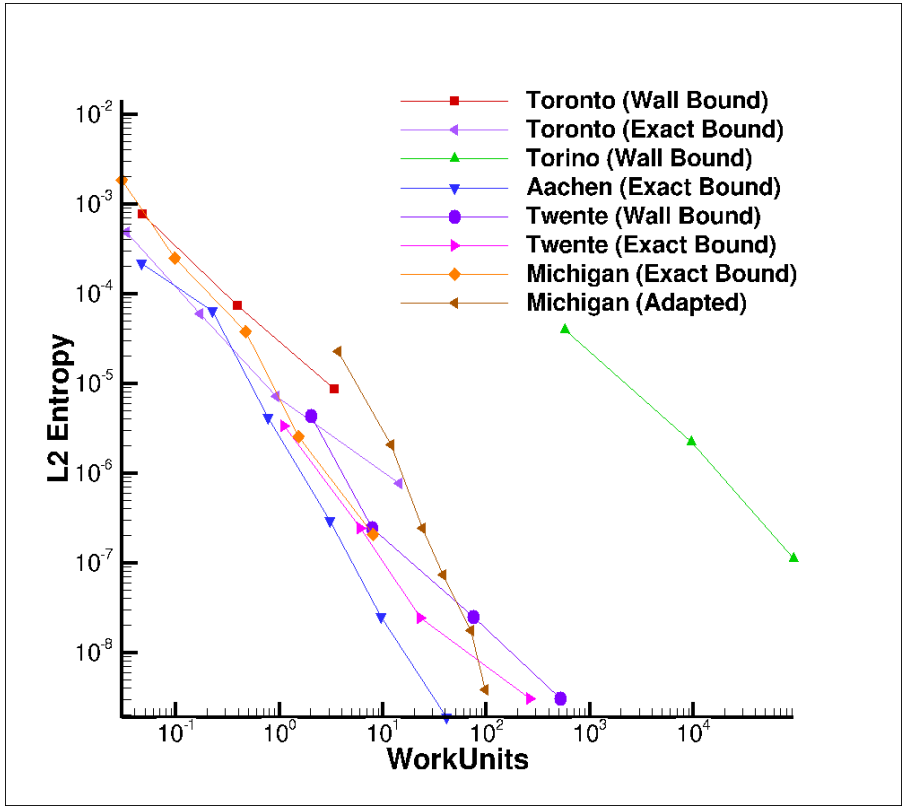


p = 2, 3rd order

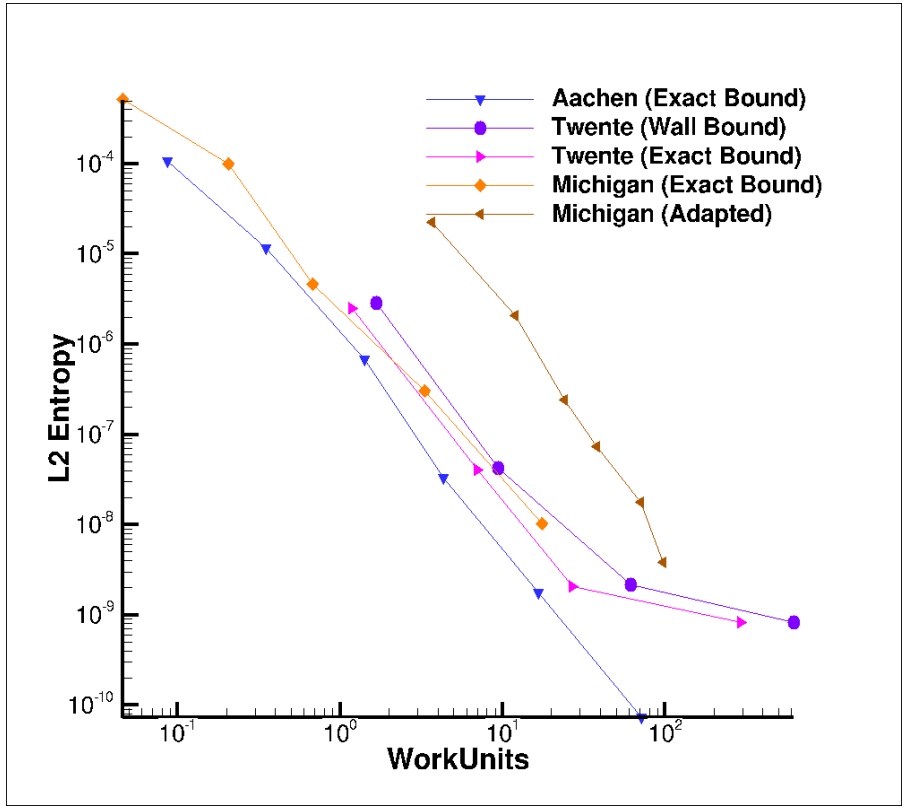


Efficiency, entropy error

p = 3, 4th order



p = 4, 5th order



Conclusions

- Accurate wall description is crucial when wall BC's are used
  - Alternative: BC's based on exact solution
- All DG methods show design accuracy
  - Question is what happens on very fine grids when wall BC's are used
- FD methods show design accuracy for 2^{nd} and 3^{rd} order schemes and 4^{th} and 5^{th} order schemes on not too fine grids
- Accuracy of 4^{th} and 5^{th} order FD scheme (Twente) on very fine grids degrade
  - Cause: Under investigation
- Both DG and FD can be made very efficient using Newton Krylov methods
- Adaption does not seem to pay off for this case (in work units)
  - It most likely will for a more complicated case