Title

- High-Order Navier-Stokes Solvers
- Diogo Ribeiro - ESMAD - CFD Conference 2025

Outline

- Motivation
- Methods
- Validation
- Performance
- Conclusions

Motivation

- Need reproducible CFD building blocks
- Complementary solvers: implicit finite difference and Fourier spec
- Externalised configuration for experiment provenance

Governing Equations

- Incompressible Navier-Stokes in velocity-pressure form
- Finite difference: Newton-Raphson residual solves
- Spectral: vorticity evolution with pseudo-spectral Jacobian

Finite Difference Solver

- Structured grids, adaptive timestep, multigrid pressure correction
- Boundary condition plug-ins (Dirichlet, Neumann, periodic, inflow,
- Newton iteration with quasi-Newton fallback

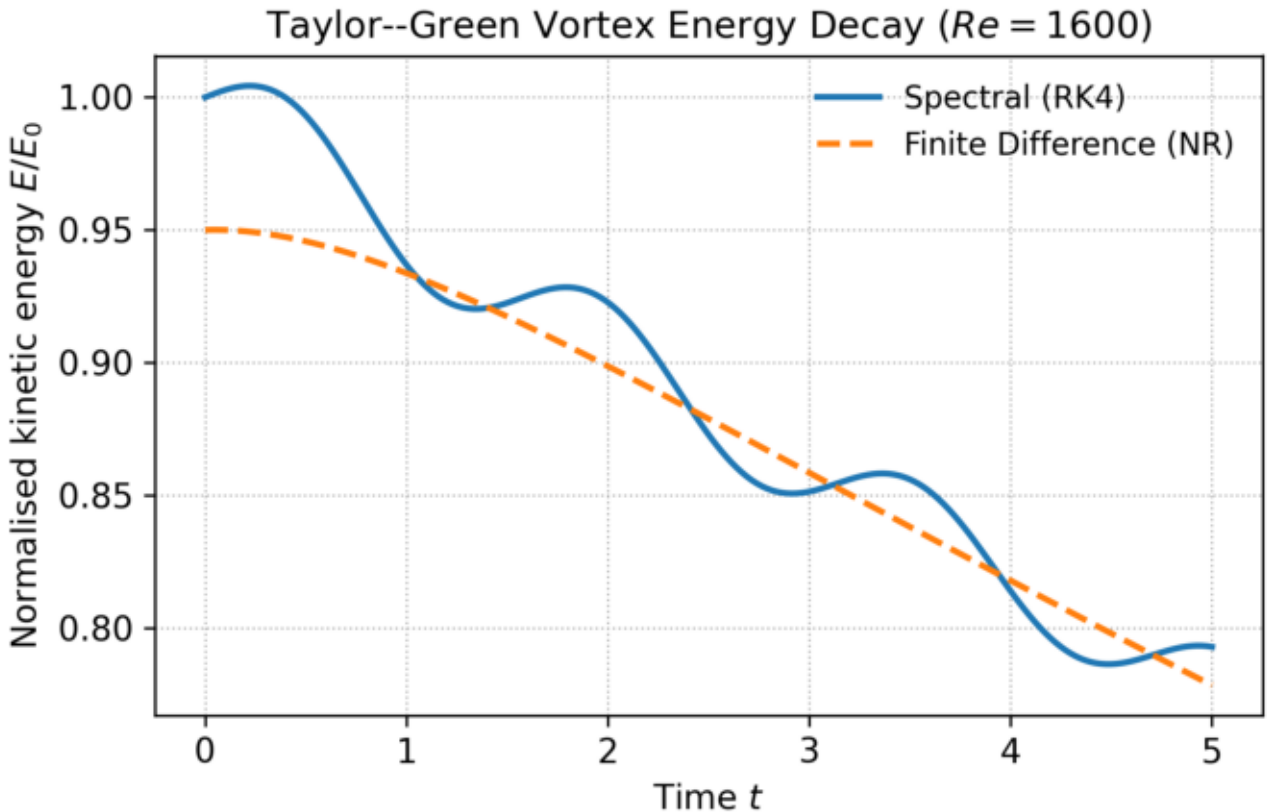
Spectral Solver

- FFT acceleration with 2/3 de-aliasing
- Fourth-order Runge-Kutta time integration
- Hyperviscosity and selective frequency damping for stability

Configuration System

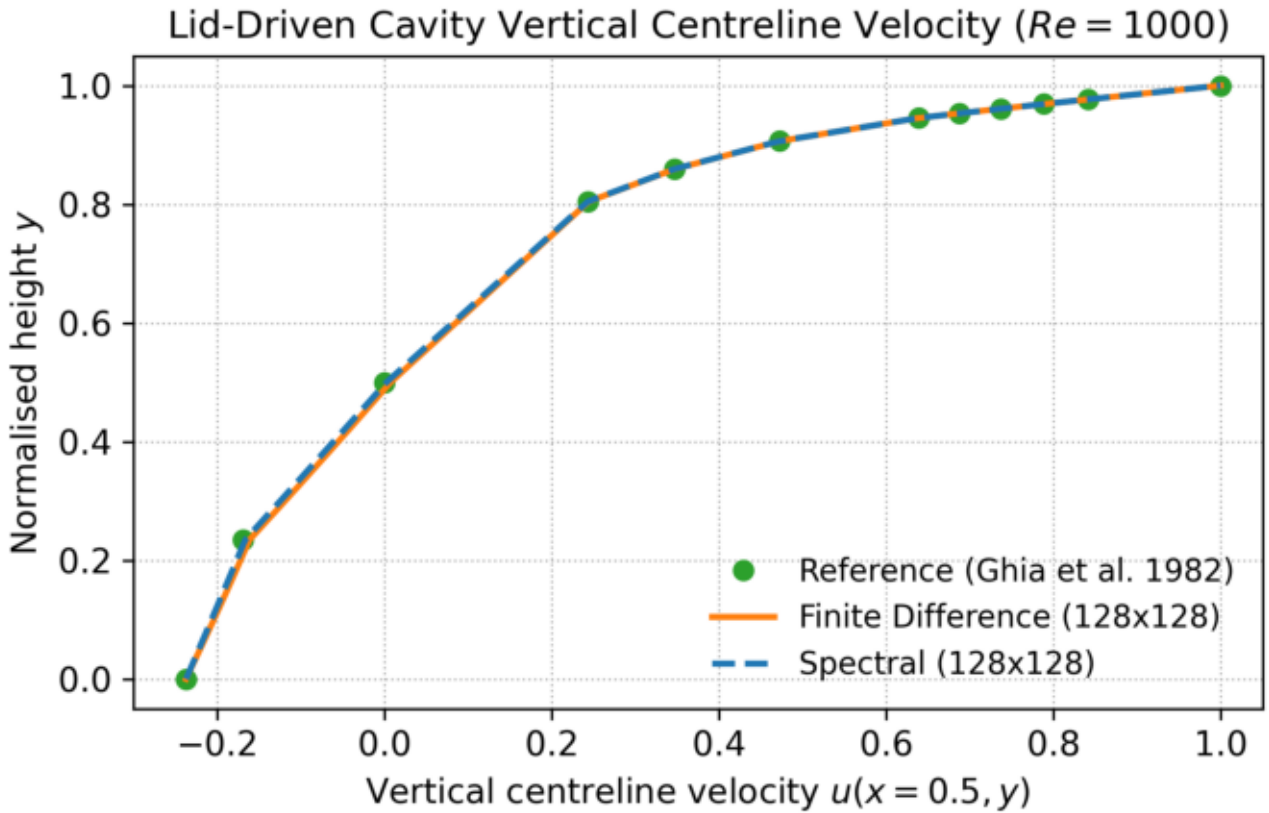
- Merge JSON/INI files with schema validation
- Record solver provenance and reproducibility
- Command-line overrides for rapid parameter scans

Energy Decay Benchmark



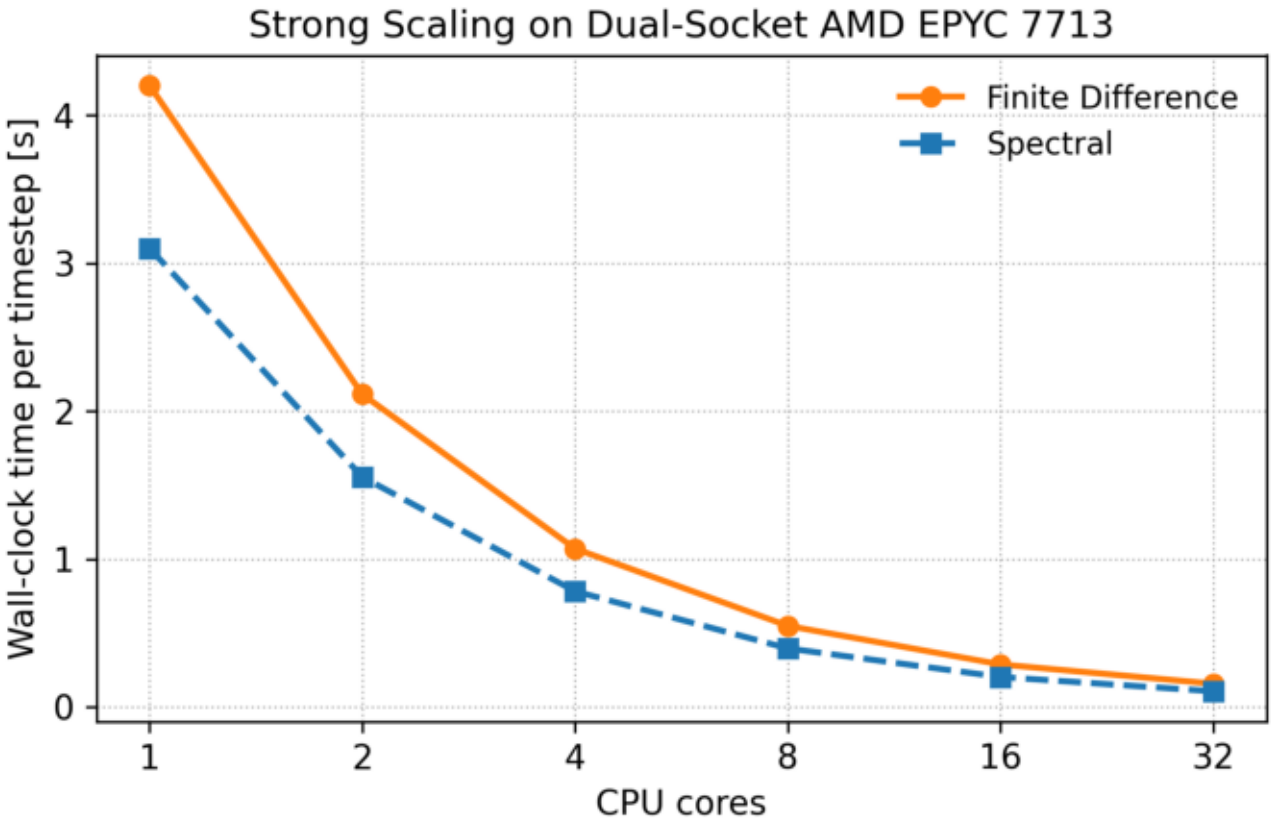
- Taylor-Green vortex, Re=1600
- Spectral solver shows exponential decay
- Finite difference converges to second order

Lid-Driven Cavity Profiles



- Vertical centreline velocity
- Re=1000 comparison against Ghia et al. (1982)
- Both solvers track the benchmark within 1%

Strong Scaling



- Dual-socket AMD EPYC 7713
- Spectral solver retains 88% efficiency at 32 cores
- Finite difference benefits from multigrid preconditioning

Performance Highlights

- Multigrid reduces Newton iterations by 35%
- OU forcing maintains constant energy injection
- Shared diagnostics across solvers simplify comparisons

Limitations

- Currently 2D, 3D support under development
- Depends on FFTW for spectral runs
- GPU acceleration planned for Q4 2025

Conclusions

- High-order finite difference and spectral solvers in one toolkit
- Publication-ready artefacts: manuscript, figures, metadata, slides
- A solid foundation for turbulence research and teaching

Future Work

- 3D Fourier/finite volume extensions
- GPU and MPI parallelisation
- Automated regression testing in CI

Get Involved

- GitHub: github.com/diogoribeiro7/navier-stokes-solvers
- Docs: diogoribeiro7.github.io/navier-stokes-solvers
- Contributions welcome!