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CHAPSim2

CHAPSim2
(CHannel And Pipe flow Simulation)

https://github.com/CCP-NTH/CHAPSim2

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CHAPSim2 is a high-fidelity computational fluid dynamics solver designed for numerical solutions of turbulence and heat transfer in canonical configurations, enabling detailed investigation of the thermal hydraulics phenomena relevant to advanced energy technologies.

Value for Research

CHAPSim2 enables researchers to perform highly resolved simulations of turbulent flow and heat transfer that are difficult or impractical to observe experimentally. The code helps improve understanding of thermo-fluid physics in unconventional fluids such as supercritical fluids and liquid metals. It also produces reference-quality datasets that can support AI/ML training and the development and validation of engineering models for nuclear energy and other advanced thermal systems. By running efficiently on modern high-performance computing platforms, CHAPSim2 enables investigation of fundamental fluid-physics problems at scales relevant to real engineering applications.

Development

CHAPSim2 was designed and developed by Dr Wei Wang at the Scientific Computing Department of STFC within the UK Collaborative Computational Project in Nuclear Thermal Hydraulics (CCP-NTH). The code is now maintained and further developed within CCP-NTH. Its capabilities have evolved through collaborations with UK universities and national laboratories, with contributions from researchers working in turbulence, heat transfer, and advanced reactor thermal hydraulics. The project forms part of the wider UK effort to strengthen high-fidelity simulation capabilities for advanced energy technologies.

Functionality

CHAPSim2 is a highly scalable, high-accuracy computational fluid dynamics solver capable of performing Direct Numerical Simulation (DNS) of turbulent flows with heat transfer, including fluids with strong variations in thermophysical properties. The solver can account for buoyancy effects and electromagnetic forces, including the Lorentz force arising in magnetohydrodynamics (MHD). It supports both Cartesian and cylindrical coordinate systems and is particularly suited for canonical geometries such as channels, pipes, and annular configurations. CHAPSim2 includes capabilities for variable-property fluids, conjugate heat transfer, and detailed turbulence analysis. The solver is designed to run efficiently on large parallel

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HPC systems using MPI-based domain decomposition, enabling simulations at very high spatial and temporal resolution. The solver is designed for efficient execution on large-scale high-performance computing systems using MPI-based domain decomposition, enabling highly resolved simulations. GPU acceleration for NVIDIA architectures is supported, enabling efficient use of heterogeneous CPU–GPU systems. The code has been performance tested on HPE Cray EX systems using up to 98,304 CPU cores, with simulations exceeding two billion computational cells, and has also been successfully demonstrated on NVIDIA H100 GPUs.

The Future

Future development of CHAPSim2 will focus on expanding its role as a community research platform for high-fidelity thermo-fluid modelling. Planned developments focus on advancing CHAPSim2 as a high-fidelity research platform for turbulence and thermo-fluid modelling. Key priorities include extending capability towards large eddy simulation, enhancing multi-physics coupling, and improving numerical methods for complex geometries, including immersed boundary approaches. Continued development will emphasise GPU acceleration and optimisation for next-generation HPC architectures. In addition, efforts will target improved data management and reproducibility workflows, alongside integration of AI/ML approaches for data-driven modelling and computational acceleration.

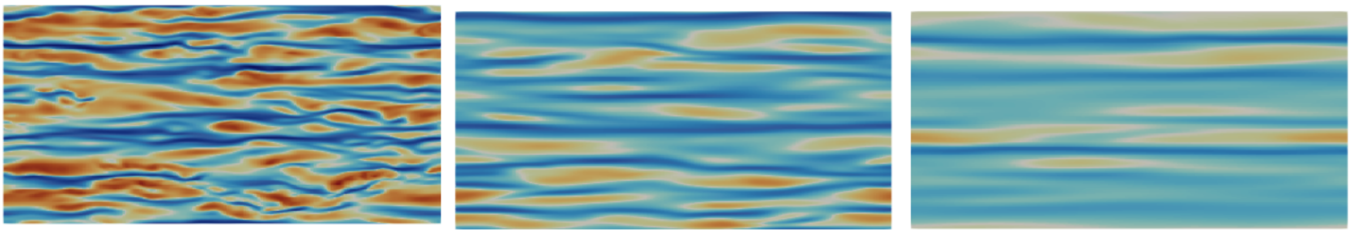

Figure: Magnetic suppression of turbulence in liquid metal

As the magnetic field strength increases, the Lorentz force damps turbulent motion and promotes more organised flow structures.

LICENCE	Programming Languages	Repository URL
BSD 3-Clause License	Fortran (core solver), Python (post-processing and utilities), Bash/Shell (workflow scripts)	https://github.com/CCP-NTH/CHAPSim2