SIMULATIONS OF MULTI-PHYSICS FLOWS

Self-Generated Magnetic Fields at Unstable Interfaces in High-Energy-Density Plasmas

Interfaces in high-energy-density (HED) plasmas subjected to abrupt changes in density, temperature, or composition are typically unstable to various types of fluid instabilities. The Rayleigh–Taylor instability (RTI), as shown in Figure 1, is a process often found in imploding HED plasmas, and it plays an important role in many stockpile stewardship applications. Recent research at LANL has shown that, during RTI development under certain conditions, magnetic fields (***B***) are generated due to the misalignment of gradients of density and pressure (or temperature). These magnetic fields can be strong enough to affect flow evolution. In the context of inertial confinement fusion (ICF) and magneto-inertial fusion (MIF), these self-generated ***B*** fields could magnetize the electrons and possibly ions (including alpha particles), therefore, affecting their heat transport and energy deposition.

The self-generation of ***B*** fields and their subsequent evolution is caused by myriad processes that interact in a complex manner, including advection by flows, diffusion and decay due to plasma resistivity, and interplay between transport of heat flux and magnetic flux. These are called extended magnetohydrodynamic (xMHD) processes, some of which amplify ***B*** fields while others dissipate them, rendering the outcome uncertain. It remains an important outstanding challenge to determine whether turbulence in HED plasmas relevant to the NNSA mission is affected by the self-generated ***B*** fields, and if so, how these effects can be modeled.

LANL scientists are investigating xMHD processes using both theory and numerical simulations to shed light on the importance and complexity of self-generated ***B*** fields. During the development of RTI between two fluids with large density and temperature differences (representative of ICF flow conditions), the growth of ***B*** fields is directly proportional to the growth of vorticity generation and kinetic energy by RTI at the unstable interface. Furthermore, as turbulent small-scale fluid motions emerge, they “twist up” the ***B*** fields, further amplifying their strength. These processes are observed in simulations where ***B*** fields are strongly correlated with regions with high gradients, as demonstrated by the density, velocity, and ***B*** fields in the bottom of Figure 1. Meanwhile, dissipative processes also become stronger with the increase of gradients, particularly in the low-temperature regions shown in the top of Figure 1, where the growth of magnetic fields is much weaker. Integrating over the whole volume, there is indeed a rapid growth of ***B*** fields along with the growth of kinetic energy from RTI (Figure 2).

Studies of this kind improve our understanding of the interactions between magnetic fields and hydrodynamic flows. Quantifications of ***B*** fields from high-resolution simulations under a variety of conditions will provide the scientific basis for including ***B*** fields in future models and improve our confidence in simulations of multi-physics flows

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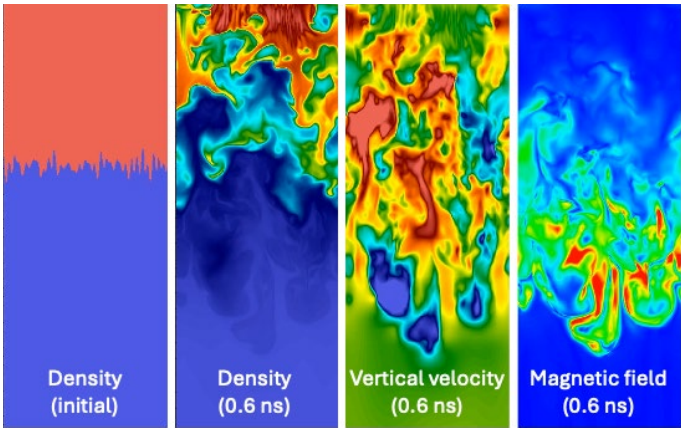

Figure 1 The interface between the heavy fluid (red) and the light fluid (blue) becomes unstable to RTI, developing finer-scale density and velocity variations. This process generates magnetic fields, which are strongly correlated with density and pressure variations. The lower magnetic field strength in the top region is partly due to the high resistivity in low-temperature plasmas.

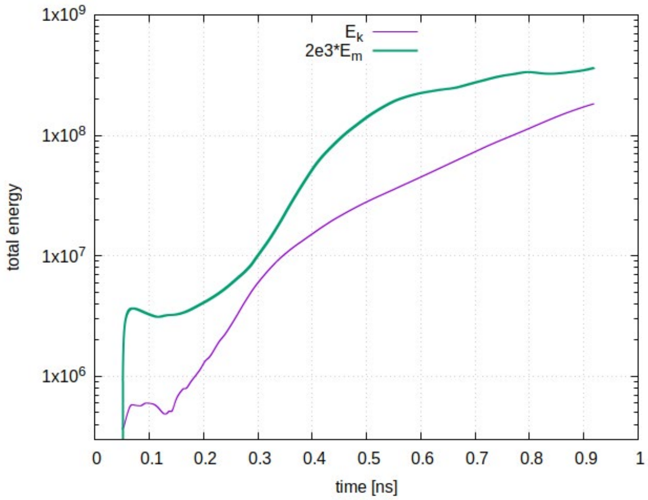

Figure 2 The growth of kinetic energy (purple) and magnetic energy (green) as RTI develops into a fully nonlinear stage shows a close correspondence. At time ~ 0.6 ns, the magnetic energy is about 3e-3 of the kinetic energy, which is large enough to affect transport of other quantities.

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NEUROMORPHIC COMPUTING ADVANCEMENT

A Neuromorphic, Spiking Backpropagation Algorithm Based on Synfire-Gated Dynamical Information Coordination and Processing

It has been argued that most modern machine-learning algorithms are not neurophysiologically plausible. In the neuroscience community, this has been claimed of the backpropagation (BP) algorithm, the workhorse of modern deep learning. However, BP is known to solve the optimization problem of how a global objective function can be related to a local synaptic modification in a network.

Figure 1 Neuromorphic deep-learning algorithm deployment could herald a low-power processing solution for artificial intelligence.

In a recent paper, "The backpropagation algorithm implemented on spiking neuromorphic hardware," a team funded by LANL's ASC Beyond Moore's Law program (among other funding sources over seven years) implemented the BP algorithm using only mechanisms that are found in the brain. This study presents a neuromorphic, spiking backpropagation algorithm based on synfire-gated dynamical information coordination and processing. The team implemented their algorithm on Intel's Loihi neuromorphic research processor.

This is the first work to show a spiking neural network (SNN) implementation of the exact BP algorithm that is fully on-chip without a computer-in-the-loop in a multi-layer context. It is competitive in accuracy with off-chip trained SNNs and achieves an energy-delay product suitable for edge computing. This implementation shows a path for using in-memory, massively parallel neuromorphic processors for low-power, low-latency implementation of modern deep learning applications. This project won a 2022 R&D 100 Award and is currently highlighted on the *Nature Communications* "**Applied physics and mathematics**"

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