11.4 The Rayleigh-Taylor Instability

2D PLUTO MHD Simulations

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PLUTO Setup

Modern codes like PLUTO are built with a large number of available modules, which users switch on based on the type of problem they want to solve.

You learned in 11.3 Activity 1 that you select the modules you wish to employ in the definitions.h file (a C include file), you define the mesh, the length of your simulation, and the output format and frequency in the pluto.ini file.

The init.c file (a C source code file) is used to define initial conditions, and boundary conditions.

Initial Conditions

Initial conditions define the state (density, pressure, velocity, magnetic field, etc.) of our simulation volume (at every zone in space) at the start of the simulation (t=0).

In PLUTO, initial conditions are set with the main Init call, and are executed once at the start of the simulation.

In today's lesson we will consider a simple initial condition: an interface separating two fluids with different densities in hydrostatic balance. Though simple to start, this leads to a classic phenomenon called the Rayleigh–Taylor instability.

For example, water, which is denser than oil, is suspended atop oil. We model the problem with two plane-parallel layers of immiscible (non-mixing) fluid; both fluids subject to the Earth's gravity.

Boundary Conditions

Boundary conditions dictate what the fluid does at the boundaries of the mesh. “These boundary conditions include inlet boundary conditions, outlet boundary conditions, wall boundary conditions, constant pressure boundary conditions, axisymmetric boundary conditions, symmetric boundary conditions, and periodic or cyclic boundary conditions. Transient problems require one more initial condition, where initial values of flow variables are specified at nodes in the flow domain.”

In our problem, the boundary conditions are reflective at the side and bottom boundaries of our square container.

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“The equilibrium here is unstable to any perturbations or disturbances of the interface: if a parcel of heavier fluid is displaced downward with an equal volume of lighter fluid displaced upwards, the potential energy of the configuration is lower than the initial state. Thus the disturbance will grow and lead to a further release of potential energy, as the more dense material moves down under the (effective) gravitational field, and the less dense material is further displaced upwards. This was the set-up as studied by Lord Rayleigh. The important insight by G. I. Taylor was his realisation that this situation is equivalent to the situation when the fluids are accelerated, with the less dense fluid accelerating into the more dense fluid. This occurs deep underwater on the surface of an expanding bubble and in a nuclear explosion.” - Wikipedia

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This problem illustrates that a simple set of initial conditions, boundary conditions, and physical processes (gravitational acceleration of two fluids of different density) leads to very complex, non-deterministic phenomena.

These phenomena arise from small seed fluctuations that are amplified as the program solves the Navier-Stokes PDEs forward in time from the simple initial condition. The remarkable (and somewhat mysterious) result is that, just like reality, each simulation is qualitatively similar, but different in detail.

Think about that next time you're stirring cream in your coffee.

Further reading: https://en.wikipedia.org/wiki/Rayleigh-Taylor_instability