

# 1D Linear Advection - Sine Wave

## Problem Specification

**Use Case.** Linear Advection

Spatial domain:  $0 \leq x < 1$  meters, periodic boundary conditions

Governing equations: 1D Linear Advection Equation

$$\frac{\partial \phi}{\partial t} = -\mathbf{u} \cdot \nabla \phi$$

Initial conditions:

$$\phi(x) = \sin(2\pi x)$$

$$\mathbf{u} = 1 \text{ m/s}$$

The Saiph's code specification can be checked at:

[From local repository]     **Click to Saiph code**

[From remote repository]     **Click to Saiph code**

## Simulation details

$$\Delta x = 1 \text{ mm}$$

$$\Delta t = 1 \text{ ms}$$

$$nsteps = 1000$$

Forward in-time integration using Euler method:  $\mathcal{O}(t)$

Spatial differentiation accuracy (default):  $\mathcal{O}(x^4)$

## Results

Output results at three time-steps,  $t = 0s$ ,  $t = 0.5s$  and  $t = 1s$  are presented in Figure 1. The  $L_2$  norm has been computed over the  $\phi$  variable taking the initial conditions as the analytic solution. The output simulation presents no truncation error  $\mathbf{L}_2 = \mathbf{0}$

The Saiph's simulation animation can be checked at:

[From local repository]     **Click to video**

[From remote repository]     **Click to video**

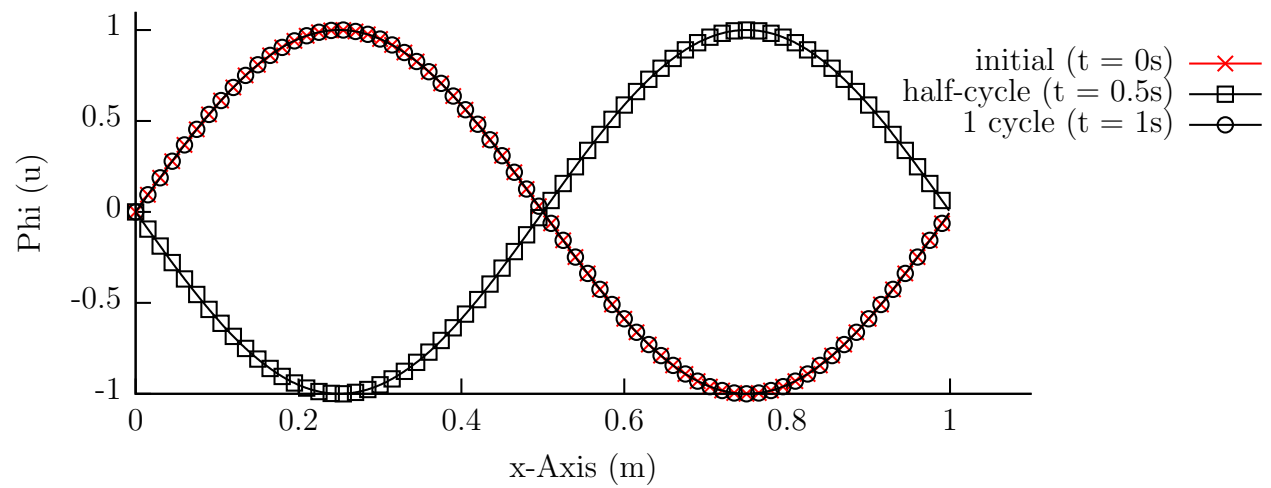


Figure 1: Phi profile at different time-steps.

# 1D Linear Advection - Discontinuous Waves

## Problem Specification

**Use Case.** Linear Advection

Spatial domain:  $-1 \leq x < 1$  meters, periodic boundary conditions

Governing equations: 1D Linear Advection Equation

$$\frac{\partial \phi}{\partial t} = -\mathbf{u} \cdot \nabla \phi$$

Initial conditions:

$$\phi(x) = \begin{cases} \exp\left(-\log(2)\frac{(x+7)^2}{0.0009}\right) & -0.8 \leq x \leq -0.6 \\ 1 & -0.4 \leq x \leq -0.2 \\ 1 - |10(x - 0.1)| & 0 \leq x \leq 0.2 \\ \sqrt{1 - 100(x - 0.5)^2} & 0.4 \leq x \leq 0.6 \\ 0 & \text{otherwise} \end{cases}$$

$$\mathbf{u} = 1 \text{ m/s}$$

The Saiph's code specification can be checked at:

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[From remote repository] [Click to Saiph code](#)

## Simulation details

$$\Delta x = 1 \text{ mm}$$

$$\Delta t = 1 \text{ ms}$$

$$nsteps = 2000$$

Forward in-time integration using Euler method:  $\mathcal{O}(t)$

Spatial differentiation accuracy (default):  $\mathcal{O}(x^4)$

## Results

Output results at two time-steps,  $t = 0s$  and  $t = 2s$  are presented in Figure 2.

The  $L_2$  norm has been computed over the  $\phi$  variable taking the initial conditions as the analytic solution. The output simulation presents no truncation error  $\mathbf{L}_2 = \mathbf{0}$

The Saiph's simulation animation can be checked at:

[From local repository] [Click to video](#)

[From remote repository] [Click to video](#)

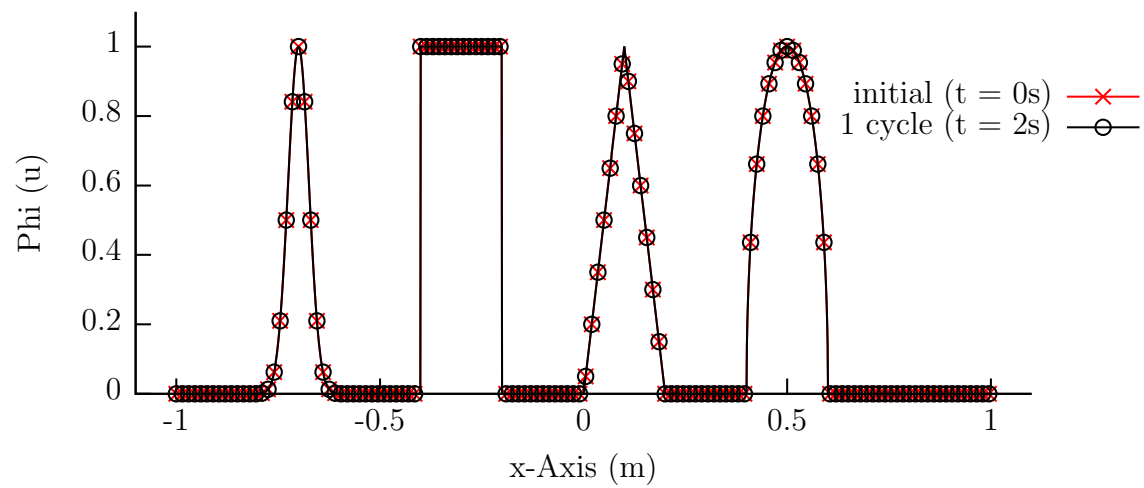


Figure 2: Phi profile at different time-steps.

# 1D Linear Diffusion - Sine Wave

## Problem Specification

**Use Case.** Linear Diffusion

Spatial domain:  $0 \leq x < 1$  meters, periodic boundary conditions

Governing equations: 1D Linear Diffusion Equation

$$\frac{\partial \phi}{\partial t} = \nabla \cdot (\nu \nabla \phi)$$

Initial conditions:

$$\phi(x) = \sin(2\pi x)$$

$$\nu = 0.001 \text{ m}^2/\text{s}$$

The Saiph's code specification can be checked at:

[From local repository] [Click to Saiph code](#)

[From remote repository] [Click to Saiph code](#)

## Simulation details

$$\Delta x = 12.5 \text{ mm}$$

$$\Delta t = 50 \text{ ms}$$

$$nsteps = 200$$

Forward in-time integration using 3<sup>rd</sup> order Runge-Kutta method:  $\mathcal{O}(t^3)$

Spatial differentiation accuracy (default):  $\mathcal{O}(x^4)$

## Results

Output results at three time-steps,  $t = 0s$ ,  $t = 5s$  and  $t = 10s$  are presented in Figure 3.

The  $L_2$  norm has been computed over the  $\phi$  variable taking the analytic solution as reference:

$$\phi(x, t) = e^{-\nu 4\pi^2 t} \sin(2\pi x)$$

The final output simulation ( $t = 10s$ ), presents an error of  $\mathbf{L_2 = 1.4 \cdot 10^{-7}}$

The Saiph's simulation animation can be checked at:

[From local repository] [Click to video](#)

[From remote repository] [Click to video](#)

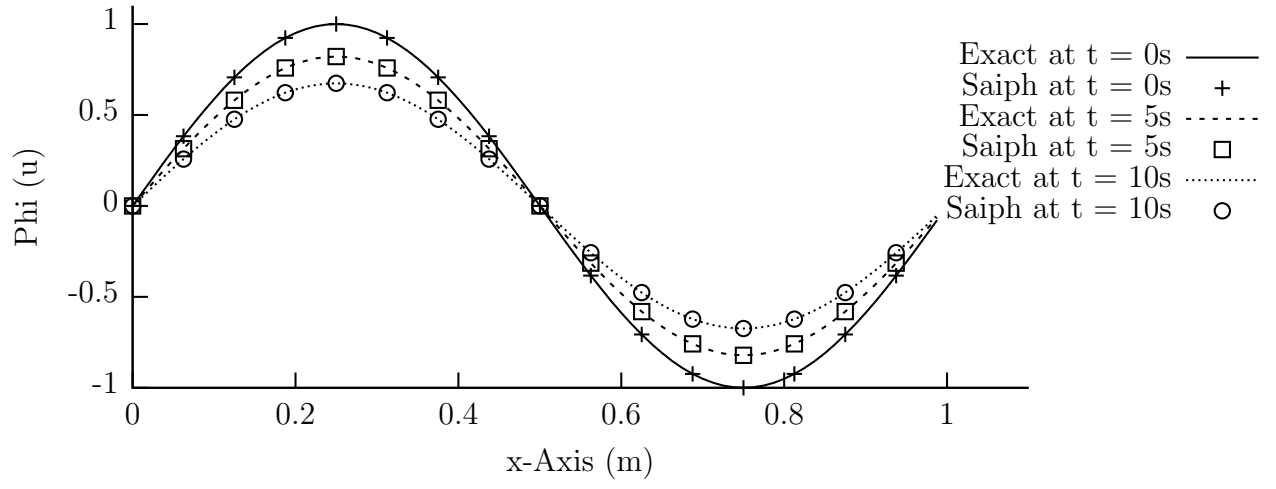


Figure 3: Phi profile at different time-steps.

# 1D Euler Equations - Sod Shock Tube

This problem corresponds to the well known shock tube originally proposed by Sod [2]. It is a transient case consisting of a one-dimensional tube, closed at its ends and divided into two equal regions by a thin diaphragm. Each region is filled with the same gas, but with different thermodynamic parameters. The fluid is initially at rest and starts to move because of the sudden breakdown of the diaphragm, the discontinuous initial condition of the left and right states entails a shock wave that propagates to both left and right sides. Figure 4 schematizes the configuration of this test [1].

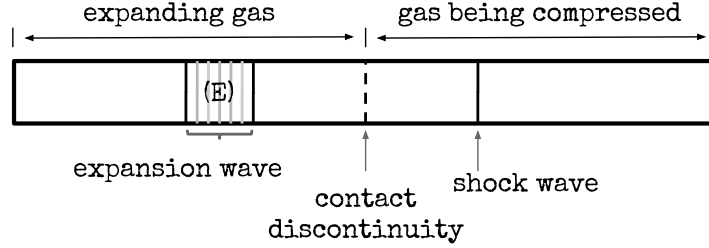


Figure 4: Schema of waves propagating in the tube after the diaphragm breakdown ( $t > 0$ ).

## Problem Specification

**Use Case.** Sod shock tube

Spatial domain:  $0 \leq x < 1$  meters

Governing equations: 1D Euler equations, continuity (1), momentum (2) energy (3) and state (4).

$$\frac{\partial \rho}{\partial t} = -\nabla \cdot (\rho \mathbf{u}) \quad (1)$$

$$\frac{\partial(\rho u_i)}{\partial t} = - \left[ \rho \mathbf{u} \cdot \nabla u_i + u_i \nabla \cdot (\rho \mathbf{u}) + \frac{\partial p}{\partial x_i} \right] \quad (2)$$

$$\frac{\partial(\rho E)}{\partial t} = - [\mathbf{u} \cdot \nabla \rho E + \rho E \nabla \cdot \mathbf{u} + \mathbf{u} \cdot \nabla p + p \nabla \cdot \mathbf{u}] \quad (3)$$

$$p = (\gamma - 1) \left( (\rho E) - \frac{1}{2} (\rho \mathbf{u}) \mathbf{u} \right) \quad (4)$$

Initial conditions:

$$\gamma = 1.4$$

$$\mathbf{u} = 1 \text{ m/s}$$

$$\rho(x) = \begin{cases} 1 \text{ kg/m}^3 & 0 \leq x < 0.5 \\ 0.125 \text{ kg/m}^3 & 0.5 \leq x \leq 1 \end{cases}$$

$$\rho E(x) = \begin{cases} 2.5 \text{ kg/m}^2 \text{s}^2 & 0 \leq x < 0.5 \\ 0.25 \text{ kg/m}^2 \text{s}^2 & 0.5 \leq x \leq 1 \end{cases}$$

$$p(x) = \begin{cases} 1 \text{ Pa} & 0 \leq x < 0.5 \\ 0.1 \text{ Pa} & 0.5 \leq x \leq 1 \end{cases}$$

Boundary conditions:

Symmetric boundary condition (Neumann BCs)

$$\frac{\partial \rho}{\partial x} = 0 \text{ kg/m}^4 \quad \begin{cases} x = 0 \text{ m}, \\ x = 1 \text{ m} \end{cases}$$

$$\frac{\partial(\rho E)}{\partial x} = 0 \text{ kg/m}^3 \text{s}^2 \quad \begin{cases} x = 0 \text{ m}, \\ x = 1 \text{ m} \end{cases}$$

$$\frac{\partial p}{\partial x} = 0 \text{ Pa/m} \quad \begin{cases} x = 0 \text{ m}, \\ x = 1 \text{ m} \end{cases}$$

The Saiph's code specification can be checked at:

[From local repository] [Click to Saiph code](#)

[From remote repository] [Click to Saiph code](#)

## Simulation details

$\Delta x = 2.5 \text{ mm}$

$\Delta t = 0.2 \text{ ms}$

$nsteps = 1000$

Forward in-time integration using 3<sup>rd</sup> order Runge-Kutta method:  $\mathcal{O}(t^3)$

Spatial differentiation accuracy (default):  $\mathcal{O}(x^4)$

## Results

Output results at final time,  $t = 0.2s$  are presented in Figure 5, against analytic solutions.

The  $L_2$  norm has been computed over the density, pressure and velocity variables taking the analytic solution as reference. The final output simulation, presents an error of

$\mathbf{L}_{2-\rho} = 1.2 \cdot 10^{-2}$ ,  $\mathbf{L}_{2-p} = 1.1 \cdot 10^{-2}$ ,  $\mathbf{L}_{2-u} = 3.7 \cdot 10^{-2}$

The Saiph's simulation animation can be checked at:

[From local repository] [Click to video](#)

[From remote repository] [Click to video](#)



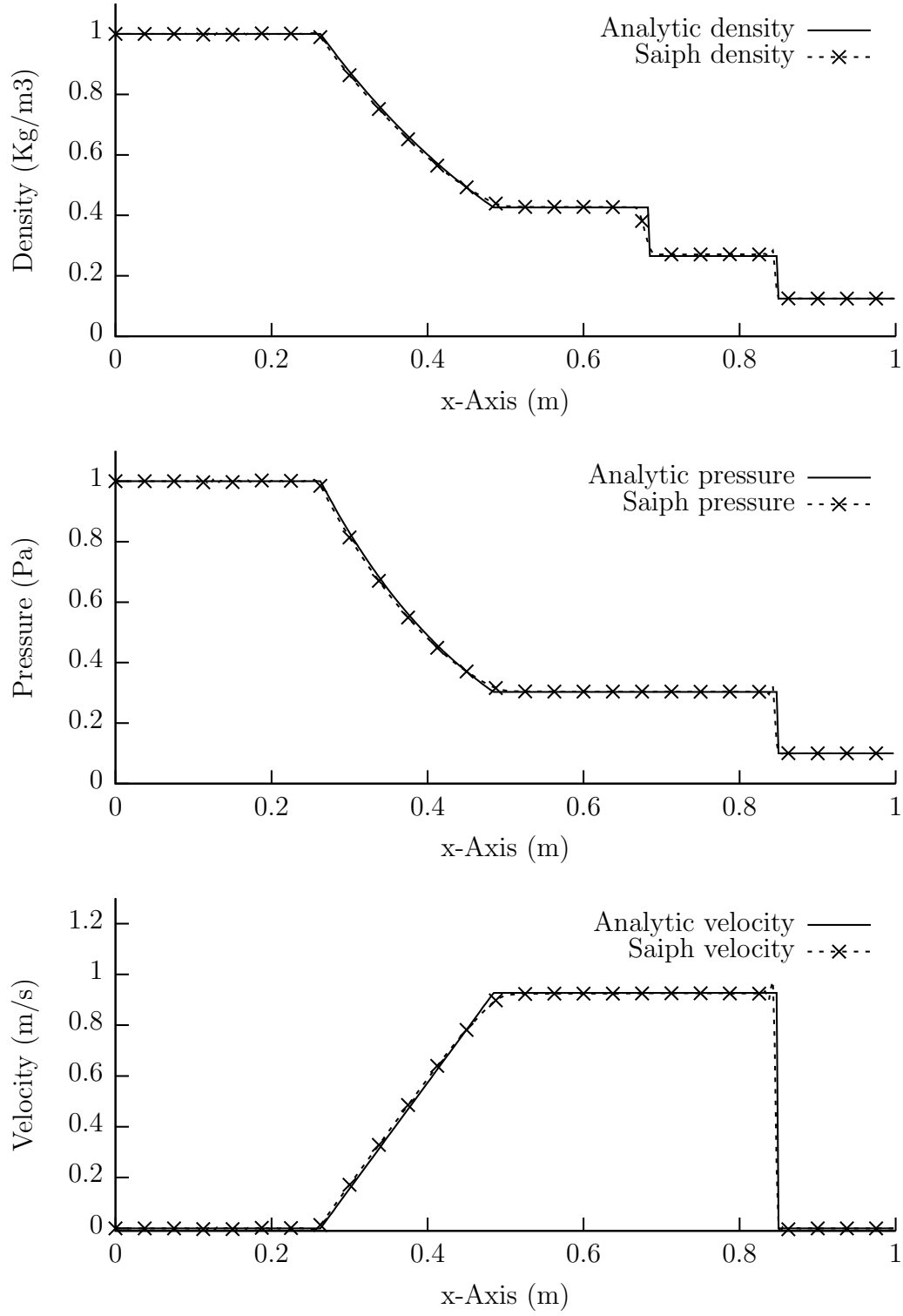


Figure 5: Variable profiles at  $t = 0.2s$  for the Sod Tube problem.



## References

- [1] MACIÀ, S., MATEO, S., MARTÍNEZ-FERRER, P. J., BELTRAN, V., MIRA, D., AND AYGUADÉ, E. Saiph: Towards a dsl for high-performance computational fluid dynamics. In *Proceedings of the Real World Domain Specific Languages Workshop 2018* (2018), ACM, p. 6.
- [2] SOD, G. A survey of several finite difference methods for systems of nonlinear hyperbolic conservation laws. *Journal of Computational Physics* 27, 1 (1978), 1–31.