Flatulence Diffusion in a Confined Space

Virtual Earth: Simulating the Environment 01

Ling Xiao

1M221091

July 21

Motivation

- Imagine nine strangers packed into a 2 m $\times$ 2 m elevator.
- A silent puff makes its debut—who's the first to notice the stench?
- Is there a scientific way to predict how quickly a puff spreads?

Research Goals

- In a 2D horizontal plane, develop a simulation of a flatulence "puff" in a confined space.
- Record when and where bystanders (detectors) first hit the smell threshold.

Physical Model Overview

- **Diffusion**: random molecular motion smooths concentration gradients.
- **Advection**: initial burst velocity + decaying "wind" transports the gas.
- **Initial Puff**: represented by a Gaussian concentration spot at the source.

We solve the 2D unsteady advection-diffusion equation:

$$\frac{\partial C}{\partial t} + \mathbf{u} \cdot \nabla C = D \nabla^2 C$$

with zero-flux boundaries:

$$\left. \frac{\partial C}{\partial wn} \right|_{\partial \Omega} = 0$$

Discretization & Numerical Scheme

- **Advection ($\mathbf{u} \cdot \nabla C$)**: Explicit upwind scheme, CFL-limited.
- **Diffusion ($D\nabla^2 C$)**: Crank-Nicolson via alternating-direction implicit (ADI) split:
  - Step 1: Implicit solve in x (fix y)
  - Step 2: Implicit solve in y (fix x)
  - **Advantage vs. Explicit Euler**: Unconditionally stable, allowing a much larger Δt for a faster simulation.

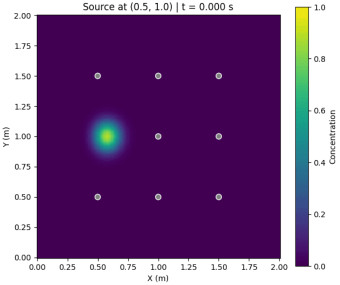
Model Parameters

- Domain: $2\,\mathrm{m} \times 2\,\mathrm{m}$, grid 200×200
- Time: total $10\,\mathrm{s}$, $\Delta t = 0.02\,\mathrm{s}$
- Diffusion coeff.: $D = \underline{1.6 \times 10^{-5}\,\mathrm{m}^2/\mathrm{s}}\,0.01\,\mathrm{m}^2/\mathrm{s}$
- Initial speed: $1.0\,\mathrm{m/s}$, decays linearly over $2.0\,\mathrm{s}$

Components of a human fart -	
Nitrogen	20-90%
Hydrogen	0-50% (flammable)
Carbon Dioxide	10-30%
Oxygen	0-10%
Methane	0-10% (flammable)

Initial Conditions & Detector Setup

- **Source locations**: 9 preset "launchpads,".
- **Detectors**: 8 fixed points, start grey (safe), turn red when $C > C_{\text{thresh}}$.
- Detection threshold: $C_{\text{thresh}} = 0.03$



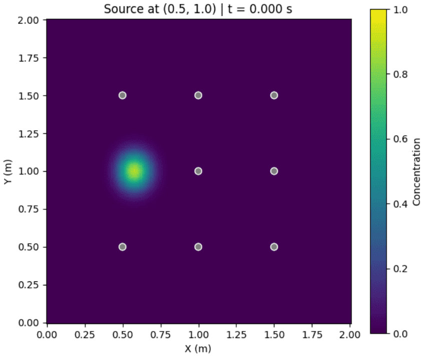


Figure 1: Source 4 (angle 0°)

Simulation Results

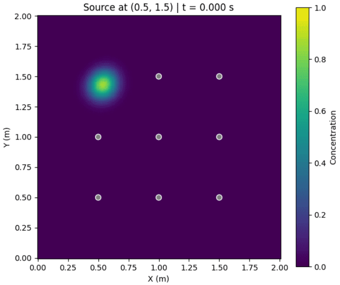


Figure 2: Source 1 (angle 300°)

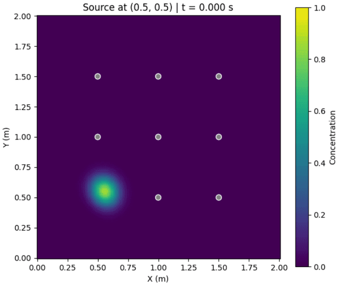


Figure 3: Source 7 (angle 42°)

Discussion, Conclusions & Future Work

- **Key insights**:
  - Burst speed & direction drastically alter who smells it first.
  - Crank-Nicolson keeps diffusion stable with larger Δt.
- **Limitations**:
  - 2D, no turbulence, constant D, linear u.
  - Real elevators have complex airflow patterns.
- **Next steps**:
  - Incorporate turbulence models.
  - Extend to full 3D to capture vertical mixing.