MOO-che Out!

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Introduction

Insects, in particular flies, are a nuisance at livestock facilities. One particular species, stable flies, bite cows which can in turn, spread disease, infection, and cause general distress. The presence of stable flies can hinder the economic success of the particular farm. To manage the fly populations, farmers introduce volatile chemicals both as attractants and as repellents. The following research models the advection/diffusion of these chemical species in a barn as well as predicting the long-term location of a fly population, based of rudimentary flight behaviour, as a result of this chemical distribution.

Background information

The research for this project began in the Forensic science department at UOIT. A few components of this research is done by entomologists to set the experimental baseline. A brief summary follows.

- Barn visit - Air samples are taken at the feet of the cows and fly counts are obtained by setting sticky traps.
- Back at the lab - Volatiles that are common among air samples are identified. These volatiles are obtained in bulk so that a electroantennogram can be performed to show the strength of a fly's response to any particular volatile.

Blasius layer

When there is a cross wind through a barn, a small boundary layer is created near the ground which develops a vertical velocity profile. This 'Blasius' layer results to resolve a no-slip condition at the floor of the barn. To solve a Blasius layer the following ordinary differential equation (ODE) must be considered

$$f''' + \frac{1}{2} f f'' = 0, \qquad f(0) = f'(0) = 0, f'(\infty) = 1. \tag{1}$$

Solving this two point boundary value problem is seen in the following figure, assuming that there is a horizontal velocity of 1 m/s. The velocity must asymptotically approach this value over a small vertically distance.

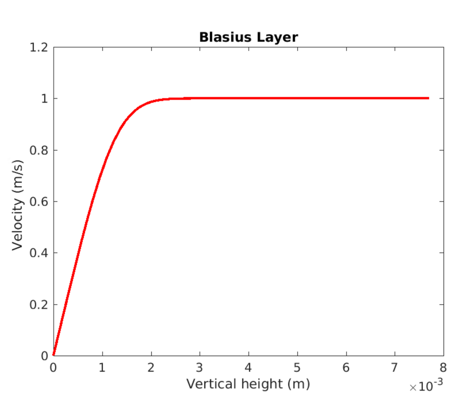


Fig. 1: The change in velocity due to the presence of a Blasius layer.

For a barn length of 40 m, with a horizontal velocity of 1 m/s, the Blasius layer is only about 1 cm thick. Above a few centimetres the velocity is essentially constant.

Concentration Model

The movement of the volatile chemicals through the barn is modelled with a conservation law for concentration,

$$\frac{\partial c}{\partial t} + \nabla \cdot (\vec{v} c) = D \nabla^2 c + S, \tag{2}$$

where S indicates a source. Sources can be either attractive (including cows) or repulsive and are ideally represented by variously located Dirac delta functions. To express their finite extent, these are replaced by Gaussians when computing the numerical solution. Neglecting any advection gives expression (3).

$$\frac{\partial c}{\partial t} = D \nabla^2 c + \sum_{i=1}^{N} \frac{1}{\sqrt{2\pi\sigma_i^2}} e^{-\frac{\vec{x}-\vec{x}_i}{2\sigma_i^2}} \tag{3}$$

The air flow through a barn is assumed to be incompressible and due to the Blasius layer, the vertical component of the velocity is insignificant.

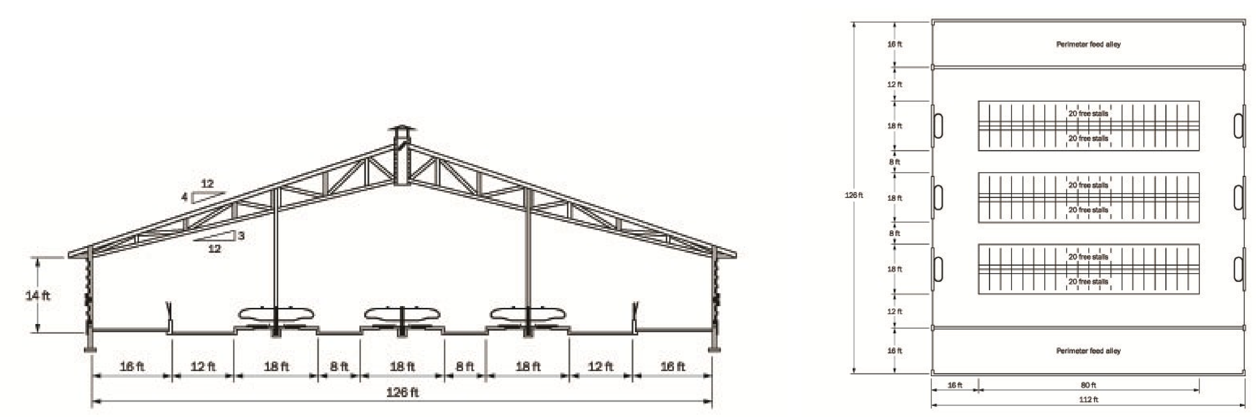


Fig. 2: 6-row with Perimeter feeding

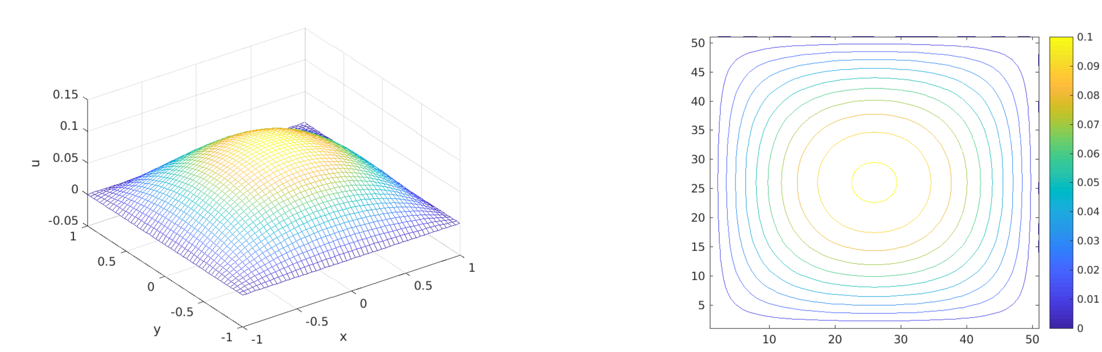
Note: blueprints from http://www.omafra.gov.on.ca/english/engineer/facts/15-015.htm

Concentration Profiles

Concentration: (no advection) If the advection piece is removed, the PDE becomes for N sources

$$D\left(\frac{\partial^2 c}{\partial x^2} + \frac{\partial^2 c}{\partial y^2}\right) = -\sum_{i=N}^{N} \frac{1}{\sqrt{2\pi\sigma_i^2}} e^{-\frac{\vec{x}-\vec{x}_i}{2\sigma_i^2}}. \tag{4}$$

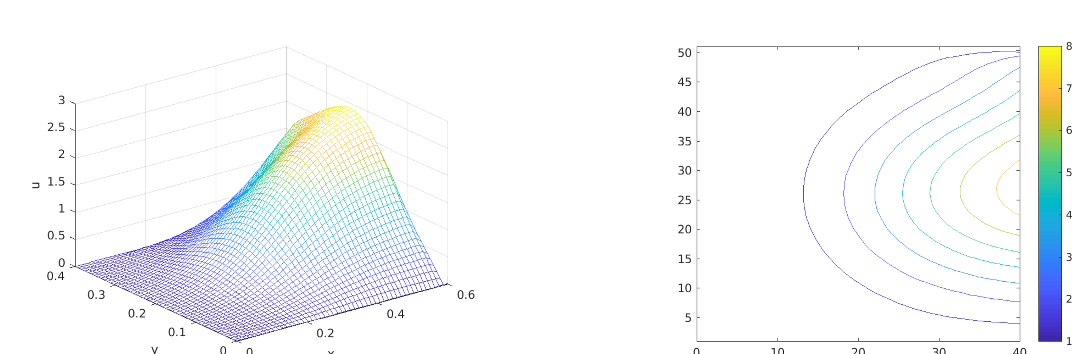
Solving this numerically using Chebyshev points, the solution with one source at the origin ($N = 1, \vec{x}_i = \vec{0}, \sigma_1^2 = 1$) is shown below.

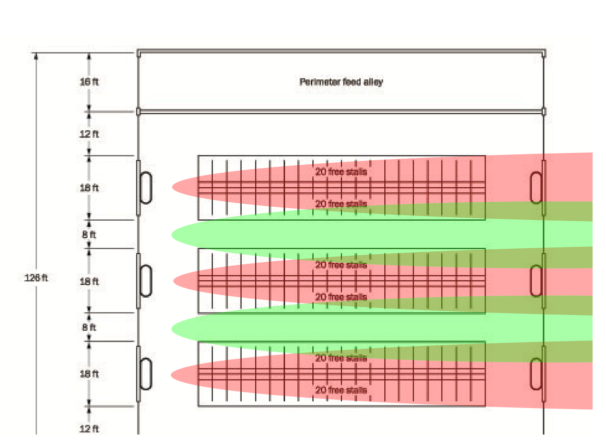


Concentration: (with advection) If advection by wind is considered only in the x direction, the equation using the incompressibility condition becomes

$$D\left(\frac{\partial^2 c}{\partial x^2} + \frac{\partial^2 c}{\partial y^2}\right) - v_0 \frac{\partial c}{\partial x} = -\sum_{i=N}^{N} \frac{I_i}{\sqrt{2\pi\sigma_i^2}} e^{-\frac{\vec{x}-\vec{x}_i}{2\sigma_i^2}} \tag{5}$$

where I_i denotes the strength of the i^{th} source. A final test case illustrates the solution with two sources. One at the origin and one in the top right corner of the barn. Beyond this patch the concentration profile does not change.

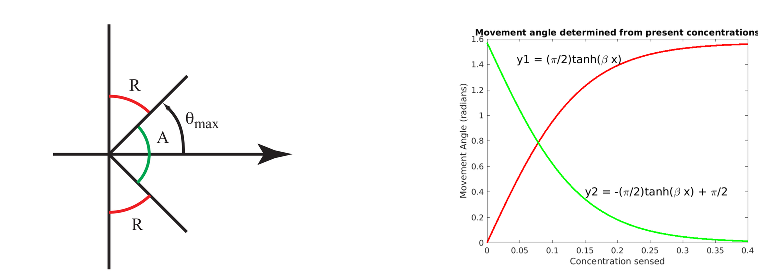




Fly Movement

The motion of a fly is governed by the local concentration of volatiles and is essentially at constant speed. The rate at which the flight path is updated increases with concentration, to a saturation level. A new direction is chosen randomly under the following constraints:

- Attractive: $-\theta_{\max} \le \theta \le \theta_{\max}$ with $\theta_{\max}$ decreasing from $\pi/2$ to zero with concentration. $\theta \to 0$ as conc. $\to \infty$.
- Repulsive: $\theta_{\max} \le \theta \le \pi/2$ or $-\pi/2 \le \theta \le -\theta_{\max}$ with $\theta_{\max}$ increasing from zero to $\pi/2$ with concentration. $\theta \to \pm\pi/2$ as conc. $\to \infty$.



Proof of concept: The figures below shows the movement of an individual fly and a collection of 1000 flies with a small Gaussian concentration profile.

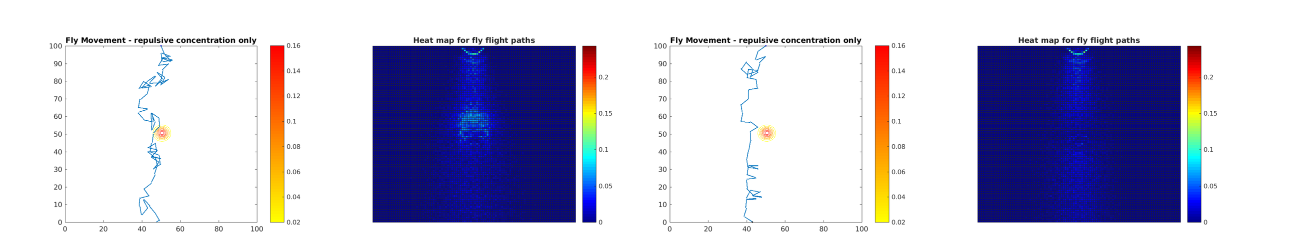


Fig. 7: Fly Movement test: left to right- single fly in the presence of an attractive concentration, many flies in attractive, single fly in the presence of repulsive, many flies in repulsive.

The heat maps show the average number of visits to a particular grid point with 1000 flies released from a uniform distribution from the barn wall. The following figure shows heat maps when many flies are released from various locations.

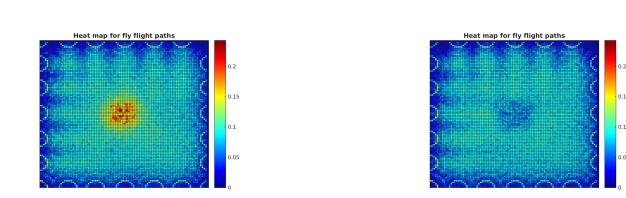


Fig. 8: Left: Many flies in the presence of an attractive source. Right: Many flies in the presence of a repulsive source.

With Concentration profile: Concentration profiles that include advection follow.

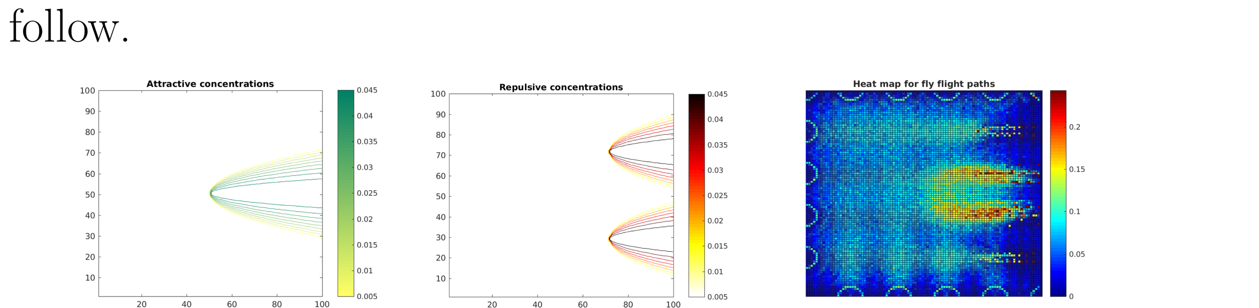


Fig. 9: Left to right: Attractive profile present, repulsive profile present, heat map of fly locations subject to the concentration profiles.

Acknowledgments

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