An Investigation of the Odor-Sensing Abilities of Moths

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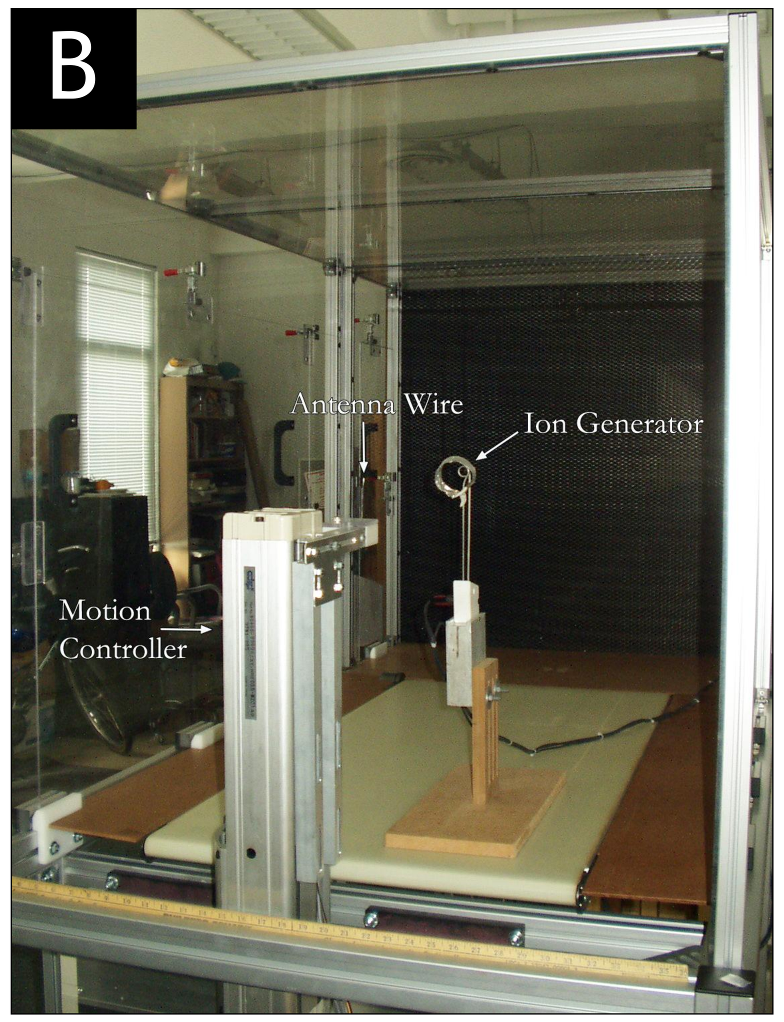
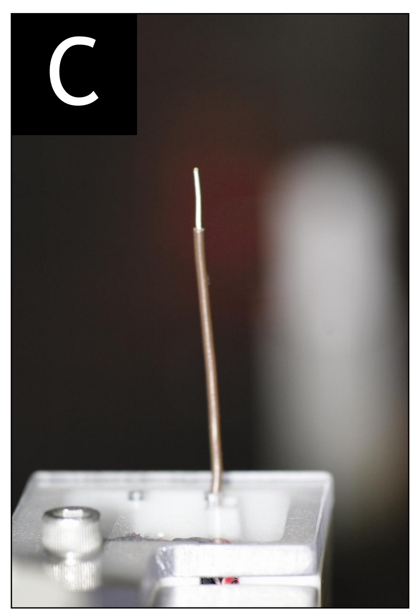
Introduction

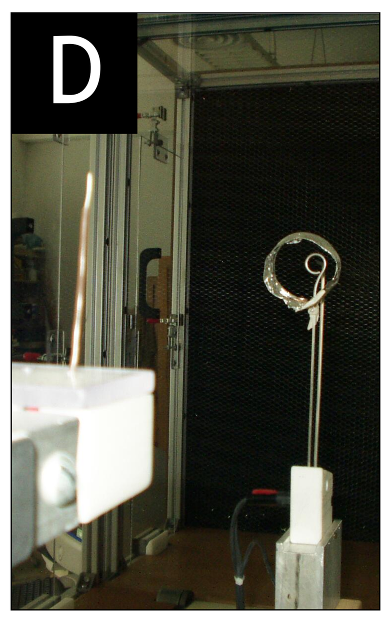
Moths are capable of tracking odors with surprising speed and accuracy. Air flows in nature, such as those the moth experiences, contain small amounts of turbulence in what are known as turbulent eddies. The sizes of these eddies are relatively unknown—they could be as small as a few millimeters or as large as several meters; however, it is these eddies that dictate the instantaneous odor concentrations that a moth uses when tracking odors. In this project, biology, statistical analysis, and experimental fluid mechanics were combined to investigate the odor-sensing capabilities of moths. Some of the questions in which we are interested can be summed as follows: Why have moths developed an odor-sensing apparatus that consists of two antennae? Do moths derive any advantages through spatial differentiation using two antennae—as humans, for example, judge depth using two eyes? How does the moth's sensation of odor concentration at one point in the plume impact its overall tracking behavior? In order to answer these and other questions, the size of characteristic turbulent eddies and the general structure of a turbulent odor plume were explored through wind tunnel testing.

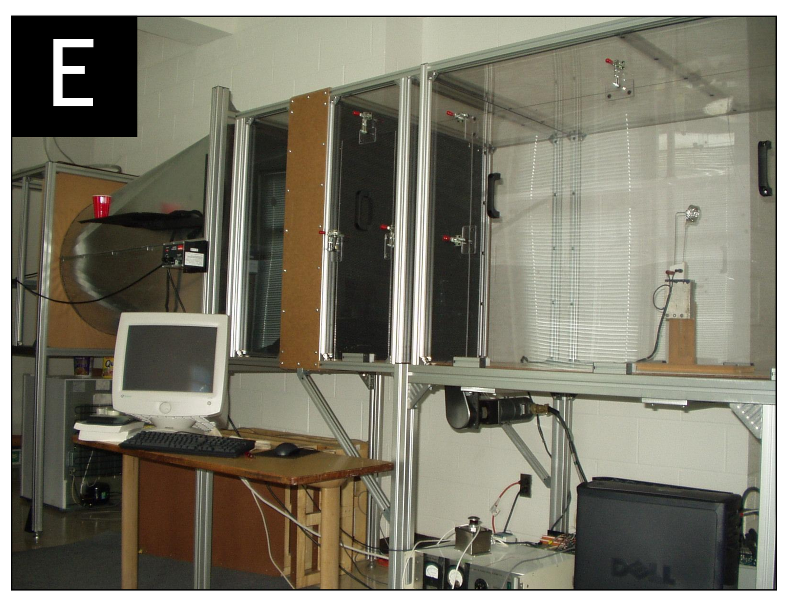
For these experiments, an odor was simulated using ionized air, and the Robo-Moth apparatus belonging to Dr. Roger Quinn of the Center for Biologically Inspired Robotics Research and Dr. Mark Willis of the Department of Biology was used to measure the resulting plume for statistical analysis.

Manduca sexta Moths and Robo-Moth







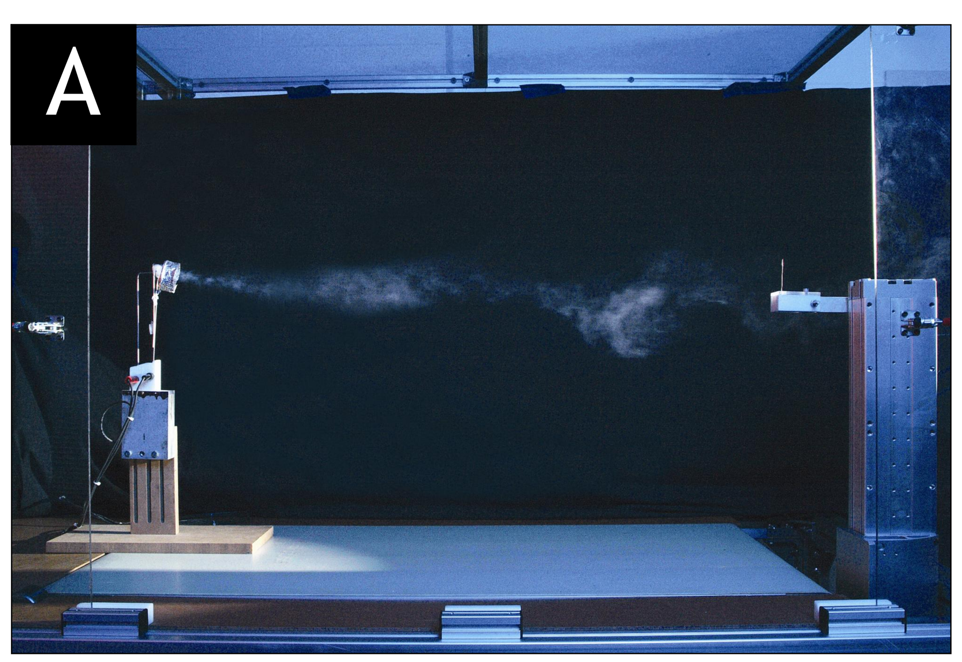


A. North American tobacco hawkmoth, *Manduca sexta;* Used to study odor-tracking behaviors. Male moths track females by following the pheromones the females release.

B – E. Views of Robo-Moth, a robot used to simulate odor-tracking behaviors. Robo-Moth tracks ions released into the air instead of tracking chemicals like pheromones.

Images A and C courtesy of Z-Med Marketing Services.

Turbulent Plumes

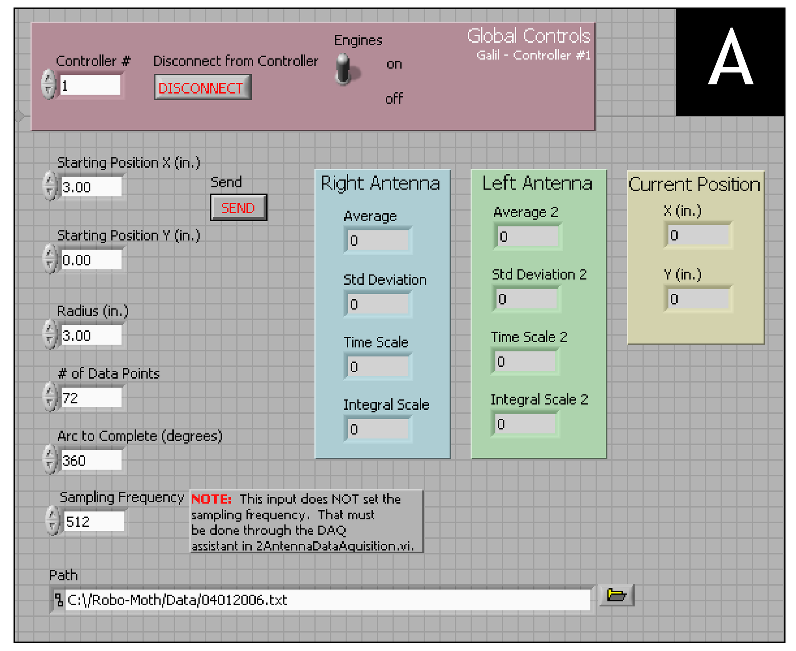


- Odors create plumes leading to their source; however, these plumes are in constant flux, making it difficult to track them.
- Studying the properties of odor plumes alongside the behavior of moths as they track odors helps us understand how they are able to track odors quickly and efficiently.

A. Turbulent plume in the Robo-Moth tunnel. This plume was created by putting titanium tetrachloride on the tip of the ion generator to visualize the flow. Although this plume is similar to the ion plume normally studied in the tunnel, it is not exactly the same.

Image courtesy of Z-Med Marketing Services.

Experimental Set-Up

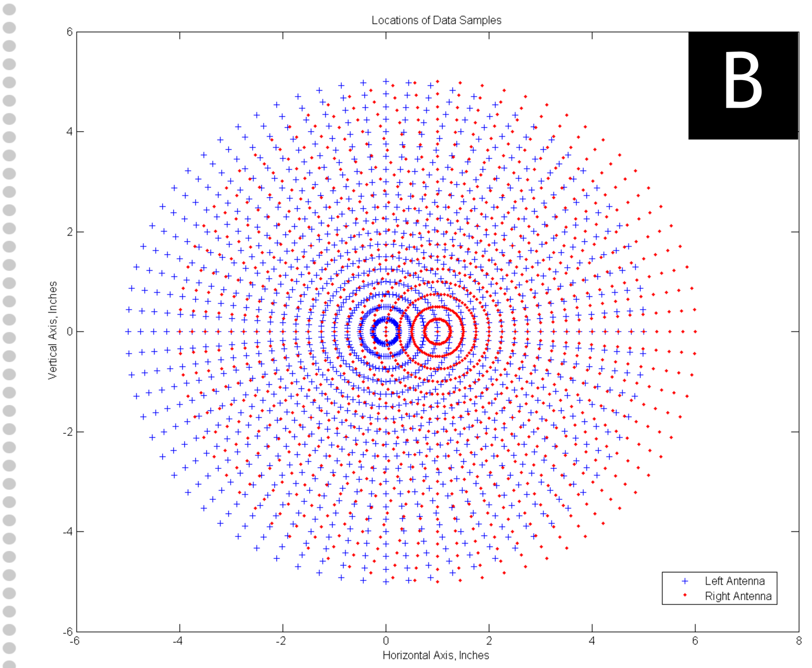


- Measuring and mapping large cross-sections of the ion plume required automation of the motion control, data acquisition, and data analysis. This was done using custom software written in LabView 7.

Mapping The Plume

Given user-defined parameters, the program shown at the left completed the following routine for more than 2,000 locations in the cross-section of the ion plume:

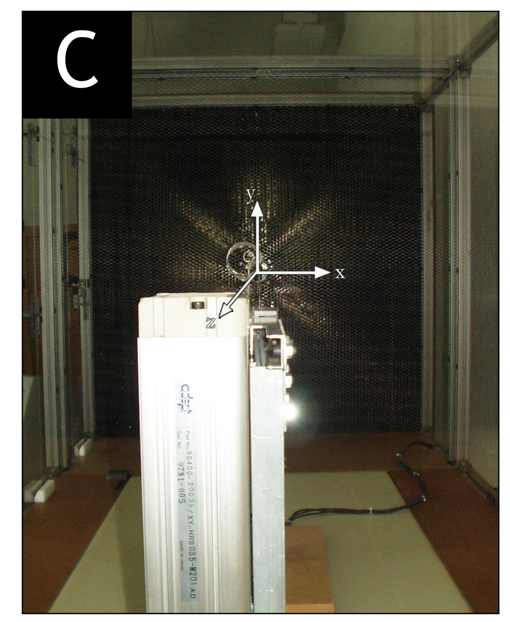
1. Calculate and execute move to next location for sampling.
2. Sample ion concentration from both antennae @ 512Hz for 8 seconds.
3. Filter noise from signals, then calculate and record the mean, standard deviation, and characteristic eddy size according to location.



A. Front panel of the LabView mapping program.

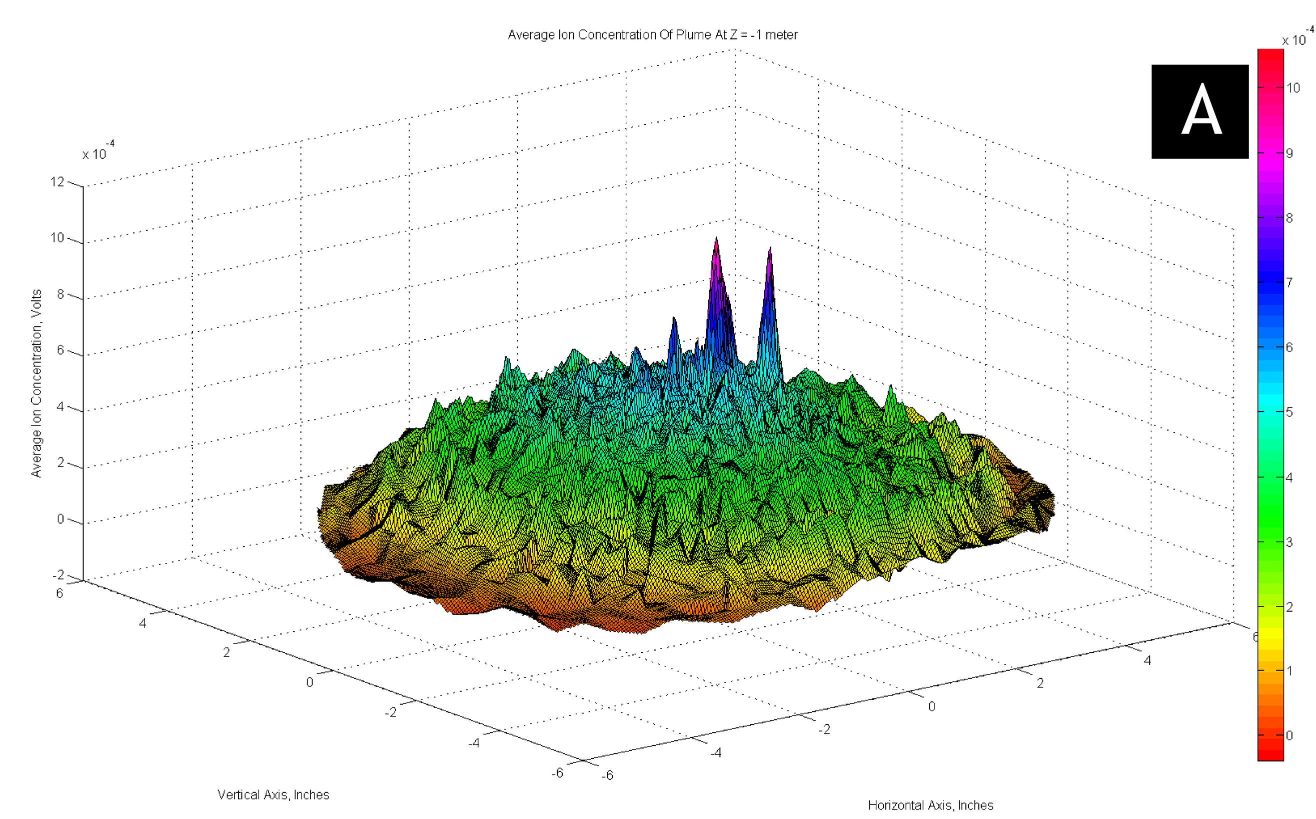
B. Map of the physical locations of sampled points.

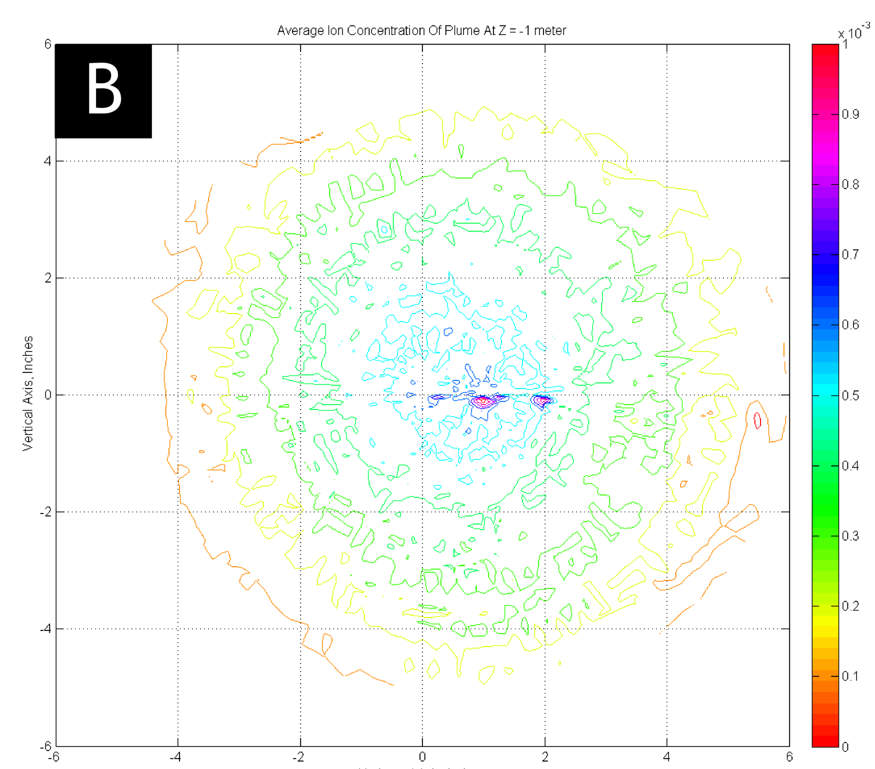
C. Coordinate system for the experiment. The location (0,0) represents the centerline of the wind tunnel test section.



Results

- Data from both antennae were combined and mapped using Matlab 7, thereby providing a full map of the data for a given cross-section of the ion plume.





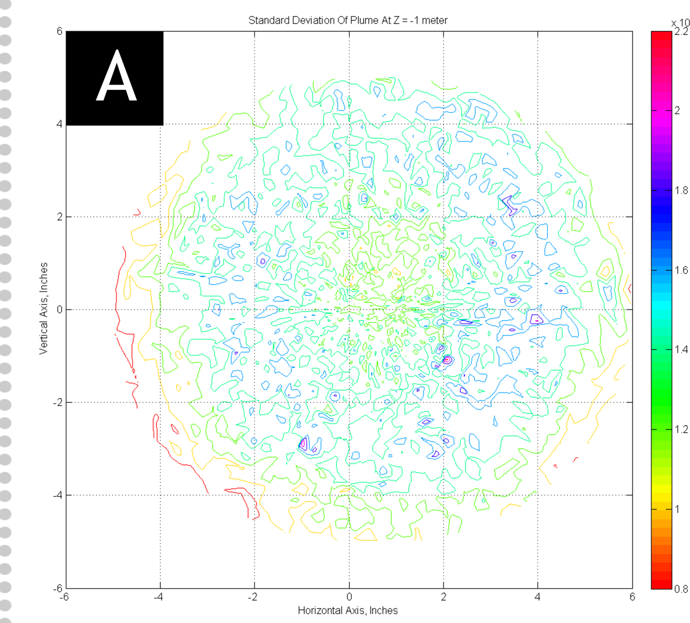
A. Surface map showing the mean ion concentration for each point in the spanwise cross-section of the plume when the ion generator is 1 meter away.

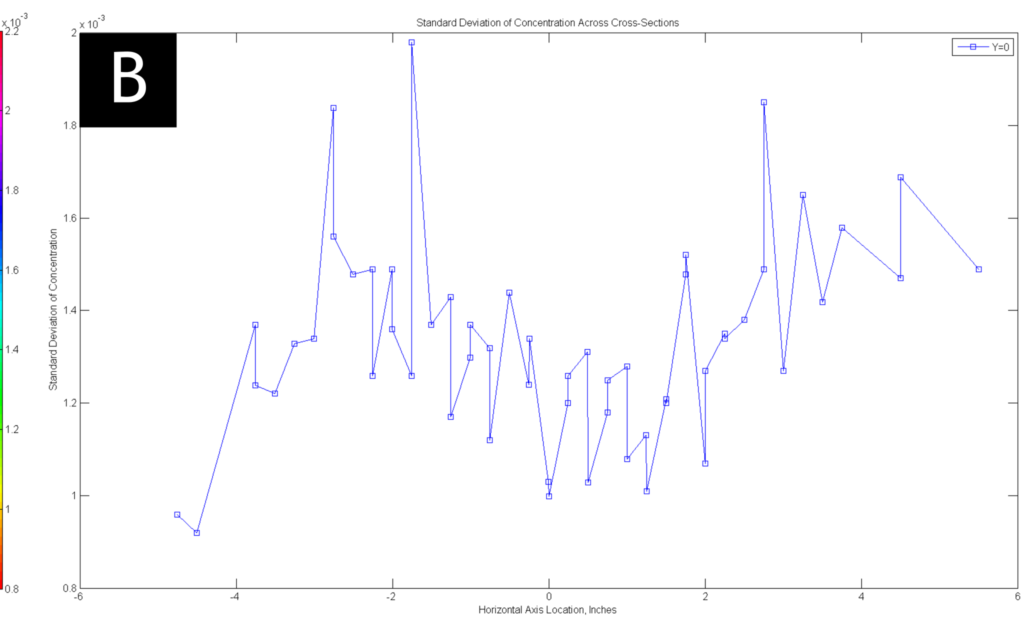
B. Contour map showing the mean ion concentration for each point in the spanwise cross-section of the plume when the ion generator is 1 meter away.

Items of Note

- Although the ion generator is on the centerline (0,0) of the wind tunnel, the center of the plume is offset.
- The plume is approximately axisymmetric about its center.
- Average ion concentrations vary very little for the first several inches from the center of the plume before dropping off rapidly.

Results (cont.)





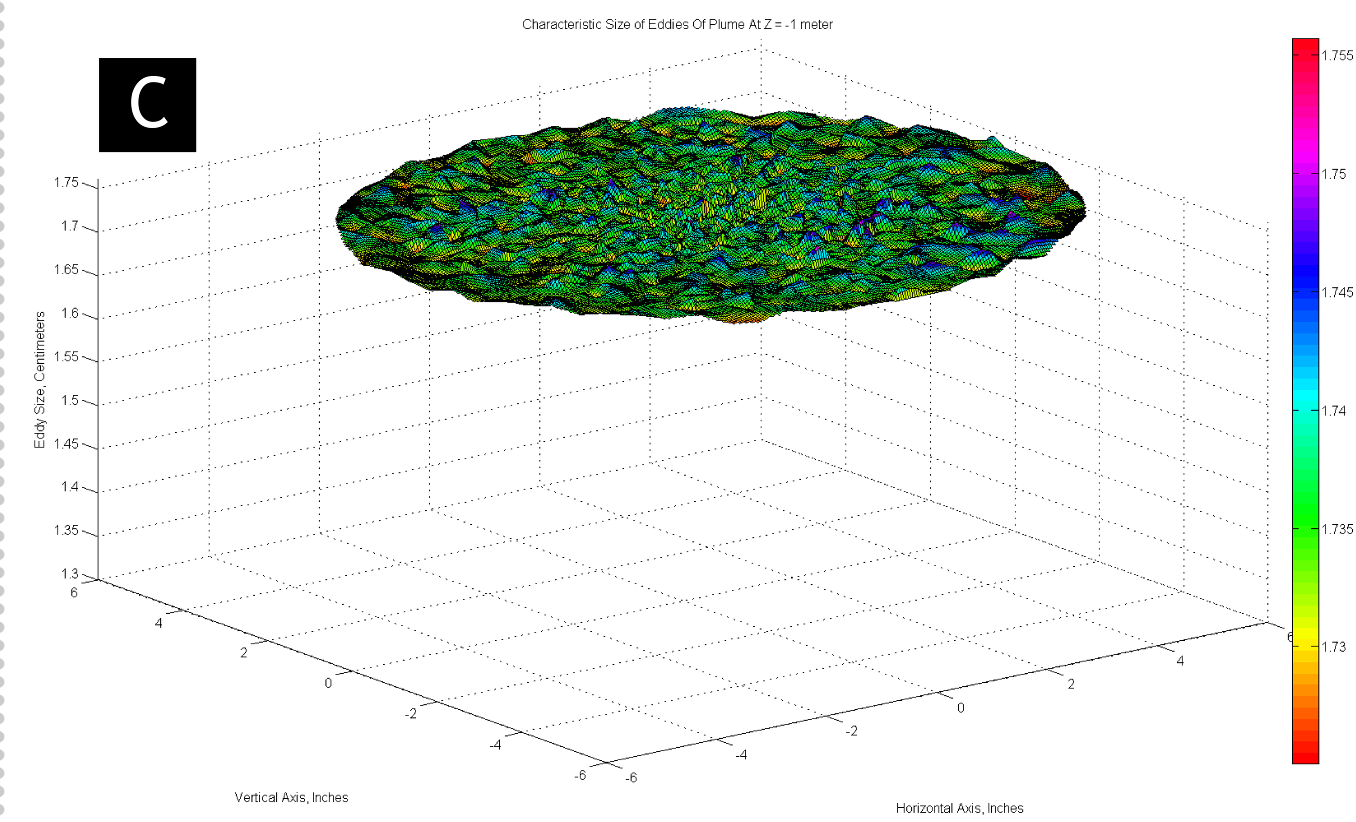
A. Contour map showing the standard deviation of the ion concentration for each point in the spanwise cross-section of the plume when the ion generator is 1 meter away.

B. A graph of the standard deviation of the concentration along the Y = 0 cross-section.

C. Surface map showing the characteristic eddy size in the z-direction for each point in the spanwise cross-section of the plume when the ion generator is 1 meter away.

Items of Note

- The standard deviation of the ion concentration, like the mean, is approximately axisymmetric.
- The standard deviation of the signal goes from low in the center to high and then returns sharply to low. It is expected that the standard deviation is closely related to the gradient of the concentration.



- Unlike the mean or standard deviation, the characteristic eddy size in the streamwise (z) direction is virtually constant (~1.73 cm) across the entire plume cross-section.

Conclusions

Mapping the ion plume has provided useful data for the continuation of the overall moth odor-tracking project. These data are particularly useful to the Robo-Moth portion of the project. Firstly, the ion plume maps provide important background, consideration of which may improve the tracking trajectories and parameters used by Robo-Moth. These, in turn, may lead to an improved understanding of how the moths themselves track odors. Secondly, the near-constant characteristic eddy size in the z-direction of 1.73 centimeters implies that moths might be able to derive spatial information with their two-antennae system. Whether this is true will depend more on the characteristic eddy size in the x- and y-directions, a topic currently under investigation.

The next step for this project is automating and mapping the spatial correlation between points in a cross-section of the plume. This will allow measurement of the characteristic eddy size in the x- and y-directions. Automated mapping of plume cross-sections and their statistical variations will also make creating a high-resolution time-averaged map of the entire ion plume feasible. It is expected that this will lend further insight into tracking behaviors and parameters.

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The authors wish to acknowledge the valuable assistance of the members of the Center for Biologically Inspired Robotics Research at Case, particularly Adam Rutkowski, as well as that of Dr. Mark Willis of the Department of Biology. This work was funded by a SOURCE Summer Fellowship during the summer of 2005.