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# A Pressure Sensitive Paint for Insect Flight Studies

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## Introduction

The long-term goal of this research project is to make quantitative measurements of the lift pressure generated by the wings of a honey bee, *Apis Mellifera*, in hovering flight. Insects generate lift during the wing-beat cycle through unsteady flapping motions. Until recently, the nature of this lift was unknown.

Our lab is using pressure sensitive paint to measure the time dependent surface lift pressure produced by a honey bee in flight. Accordingly, we have developed a new pressure paint for this project. This paint is applied as a 2-micron film to the epicuticle layer of the wing. Most of the bees survive the application procedure and are able to fly. The paint renders their wings phosphorescent and sensitive to oxygen partial pressure.

## Background

Conventional flow visualization techniques have been used to examine flow around an insect's wing during tethered flight (1). Flow visualization of hydrodynamically scaled dynamic models has also been used to study insect flight (2). These experiments have led to a better understanding of the unsteady flow during the wing-beat cycle. Unfortunately, flow visualization techniques are qualitative in nature and thus not suitable for calculating lift forces. Making quantitative measurements and obtaining a time-dependent map of pressure at the surface would allow lift force calculations to be made.

In the late 1980s the Callis/Gouterman lab in the chemistry department of the University of Washington developed pressure sensitive paint for mapping the pressure on aerodynamic surfaces (3, 4). The surface is coated with the pressure sensitive paint, an oxygen-sensitive phosphorescent dye in an oxygen permeable polymer, and measurements are made by exposing the surface to varying pressures. As the pressure at the surface increases, the phosphorescence of the paint is quenched and the intensity of the phosphorescence decreases. As a result the intensity of the emitted light is inversely proportional to the pressure at the surface. A CCD camera captures the phosphorescent images and the lift pressure is determined. This technique is being used in wind tunnels throughout the world to obtain a continuous map of pressure on the surfaces of airfoils, cars, missiles, and jets.

Our lab is working to further develop this technique so it can be used to study unsteady flows and flexible boundaries, e.g. to measure the time dependent surface lift pressure produced by a tethered honey bee in hovering flight. This is a daunting experimental problem because the pressure changes are small and modulated on a time scale on the order of one-tenth of the wing beat cycle. In addition the paint must be biocompatible (i.e. the bee must survive the painting process and be able to fly).

## Methodology

The first phase of this project focused on developing a new paint that is suitable for insect flight studies. Initial experiments with existing paints showed they were too stiff to allow the bee to fly, they did not respond on a fast enough time scale, and were insufficiently sensitive for low-speed aerodynamics. For our application the paint must respond in 0.50 ms and detect pressure changes of 0.15 torr superimposed on 760 torr steady-state pressure. Accordingly, a new pressure sensitive paint has been developed for this project. This paint is applied as a 2-micron film to the top layer of the wing. The paint renders their wings phosphorescent and sensitive to oxygen partial pressure.

Paints developed from various combinations of nine polymers and ten phosphorescent sensors were tested for this application. The best paint proved to be a solution of platinum tetrafluorophenyl porphine in beeswax. Beeswax is a natural choice for the polymer because the bee's wings become coated with a thin layer of beeswax in the hive. In addition to the aforementioned biocompatibility, the response time and sensitivity are within our requirements.

**Results**

A new pressure sensitive paint has been developed that is suitable for insect flight studies. The paint renders the bee's wings phosphorescent and sensitive to small changes in oxygen partial pressure. The paint has also been shown to respond on the time scale necessary for this application. Most of the bees survive the painting procedure and are capable of sustained flight.

**Discussion**

Future work includes developing new methodology and instrumentation for making continuous measurements of the surface pressure of an insect's wings during flight. Currently available CCD cameras have one or more of the following deficiencies: (a) insufficient signal to noise ratio due to limited full-well charge storage capacity, (b) inability to respond rapidly enough, and (c) inability to capture two images of sufficient resolution in quick succession. Lifetime imaging instrumentation based on a new generation of CMOS video devices will be developed that is capable of measuring small and rapid intensity changes. In addition a solid-state laser-based flash illumination method will be developed in which the camera shutter and laser-pulse are phase-locked to the wing-beat cycle.

After quantitative measurements are made and a time-dependent map of pressure at the surface is obtained, colleagues at the Courant Institute of Mathematics at New York University will use the data to test fluid dynamic calculations. These researchers are leaders in the simulation of unsteady three-dimensional flows interacting with moving boundaries. Collaborations with this group will allow quantitative comparisons of theory with experiment that may lead to verification of insect flight theory not currently possible.

**References**

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