MILLER INSTITUTE NEWSLETTER

Spring 2005

Miller Fellow Focus: Stacey Combes

First year Miller Fellow Stacey Combes studies the biomechanics of insect flight. She combines physics and computational modeling with evolutionary biology and behavior to understand how insects – the most diverse and abundant group of animals on our planet – are able to zip, dodge and weave through a complex and unpredictable aerial environment. She is hosted by Professor Robert Dudley in the Department of Integrative Biology.

Flying insects perform feats that would put many aerospace engineers to shame – they speed forward at hundreds of bodylengths per second, fly backwards and sideways, hover in mid-air, and execute 90-degree turns in mere milliseconds. These abilities help determine whether a flying insect finds enough to eat or becomes a meal itself, and whether it can defend a territory or attract a mate. Ironically, we learned how to build airplanes that could fly through the air long before we gained a thorough understanding of how animals accomplish the same task. Thus, when early attempts to understand insect flight by applying our knowledge of airplanes failed, the urban legend that scientists had proven "bumblebees can't fly" was born.

Actually, bumblebees can fly – but amazingly, the way they do so has become clear only in the last decade or so. The smooth, "steady" flow of air that glides continuously over an airplane wing rarely occurs in insects, who flap their wings forward and back 20 to 600 times per second. Instead, insects use a whole variety of "unsteady" tricks to generate the lift forces that keep them aloft – flapping with wings tipped at dangerously steep angles to generate extra lift from an unstable vortex riding on top of the wing, rotating their wings while they are still moving (like hitting a tennis ball with backspin), and plunging their wings through the swirling wake that was shed at the end of the previous stroke.

Because most insects are too small and beat their wings too rapidly for direct force measurements, much of our understanding of unsteady aerodynamics has come from scaled physical models (giant, robotic insects) or computational studies, in which insect wings are assumed to be rigid plates - but in reality, insect wings bend, twist and wave dramatically during flight. We know that small changes in the shape of airplane wings (such as lowering the flaps) affect how much force the wings produce, but we have no idea how the large, continuous shape changes that occur in flapping insect wings affect the unsteady aerodynamic tricks that insects use. Before this question can be answered, though, we need to know more about insect wing bending. Insect wings

have no active muscles past their base, so bending is passive - but how flexible are wings, how does their structure affect the way they bend, and what types of forces actually cause wing bending?

These questions were the focus of Stacey's thesis work with Tom Daniel at the University of Washington. She started by performing bending experiments on a diversity of wings, and found that the main determinant of overall stiffness is simply wing size - surprisingly, large evolutionary changes in the arrangement of supporting wing veins do not affect overall stiffness. Next,

continued on page 2

Deadlines To Note:

Thursday, September 15
Miller Fellowship nominations due
Note new deadline date!

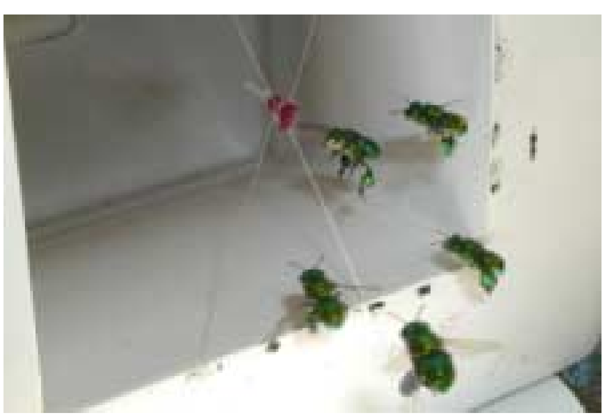
Thursday, September 22
Miller Professor applications due

Monday, September 26
Visiting Miller Professor nominations due

INSIDE THIS EDITION

Stacey constructed "maps" of how stiffness varies spatially in wings, by visualizing bent wings with lasers and back-calculating the distribution of stiffness that would account for the observed bending patterns. These maps are strikingly similar in both hawkmoths and dragonflies, with a sharp decline in stiffness towards the tip and rear edge of the wing. Stacey created a virtual (finite element model) hawkmoth wing based on these measurements, and found that this pattern of stiffness localizes bending to the wing margins, where force production is likely to be most sensitive to changes in shape. A final piece of the wing bending puzzle was figuring out which forces actually cause insect wings to bend during flight - the aerodynamic forces that hold an insect in the air, or the inertial forces generated by rapid wing accelerations. To tease apart these forces, Stacey filmed fresh hawkmoth wings flapped by a motor in both normal air and in low-density helium. Because the deformations of the wing were nearly identical, the experiment showed that inertial forces (which are independent of fluid density) dominate in producing wing deformations – a fortunate result for future aerodynamic modeling, since inertial bending is much easier to predict.

After spending years thinking about flapping and bending, Stacey decided to forego the glamour of insect wings and focus on the often-neglected body itself. Most studies of insect flight have been performed on tethered insects hovering or flying "forward" in a wind tunnel, and few significant movements of the abdomen, legs and other body parts have been seen. Tethered locusts that are played predatory noises from one side do throw their legs and abdomen to the other side, apparently "steering" to avoid the approaching threat. But the extent to which insects routinely move their abdomen, head and legs during free, maneuvering flight, and how these movements affect their flight trajectory is unknown.



Orchid bees flying at the mouth of the wind tunnel.

Stacey in Panama with her wind tunnel, waiting to net a bee after it flies at its maximum forward speed.

While finishing up in Seattle, Stacey built a robotic flower that oscillates up and down, enticing a hungry hawkmoth to follow. Reconstructed three-dimensional coordinates of the head, thorax and abdomen reveal that freely flying hawkmoths do flex their abdomens up and down as they follow the flower. This flexion changes the body's center of mass significantly, which should pitch the body up or down during flight and allow the moth to steer with its abdomen. But surprisingly, the videos show that moths flex their abdomen in the opposite direction from what would be expected if they were using it to steer up and down. Instead, moths pitch up or down by changing their wing motions, and a short time later, they flex their abdomen in the opposite direction to slow this rotation. So, when maneuvering up and down, moths are actually using their abdomen as a brake to stop movements initiated by the wings. Stacey is currently analyzing videos of moths following flowers from side to side, to see if moths use their abdomen as a brake in lateral maneuvering as well, or if they use it to steer left and right, as tethered locusts do.

Stacey is also taking advantage of the field expertise of her host, Robert Dudley, to move her work one step closer to reality – switching from lab-raised moths flying freely in a box to wild orchid bees flying in the open air of the tropics. These colorful, iridescent bees are strongly attracted to (one could even say obsessed with) collecting pleasant odors that they scrape from orchid petals and store in their enlarged hindlegs, presumably to attract mates. Luckily, similar bottled odors (such as cinnamon, eucalyptus and vanilla) summon orchid bees from the forest and persuade them to cooperate with researchers. Last spring, Robert and Stacey collected preliminary data on maximum forward flight speed in orchid bees, who will continue to

continued on page 7, see "Combes"

Visiting Miller Professorship Awards
Spring Competition

Each year, the Miller Institute holds two competitions to select Visiting Miller Professors for the following academic year. The following Visiting Miller Professors were selected during the spring competition cycle. The purpose of this program is to bring promising or eminent scientists to the Berkeley campus for collaborative research interactions.

Douglas Abraham University of Oxford, UK	***Chemistry***
Daniel Eisenstein University of Arizona	***Physics***
Jules Jaffe University of California, San Diego	***Integrative Biology***
Ursula Keller Eidgenössische Technische Hochschule Zürich, Switzerland	***Physics***
Lakshminarayanan Mahadevan Harvard University	***Chemical Engineering***
David Milstein Weizmann Institute of Science, Israel	***Chemistry***
Carl Pabo Stanford University	***Molecular & Cell Biology***
Alexandre Tsybakov University of Paris VI, France	***Statistics***
Eric Vanden-Eijnden New York University	***Mathematics***

Miller Research Fellowship Awards 2005-2008

The Miller Institute is pleased to announce the 2005-2008 Miller Research Fellows. Each year, the Miller Institute seeks to discover individuals of outstanding talent and to bring to Berkeley young scholars of great promise. Candidates are nominated for these awards and are selected on the basis of their academic achievement and the potential of their scientific research. They will be working with Berkeley faculty for a three-year term beginning in the 2005 academic year.

Philip Chang

Ph.D. University of California, Santa Barbara
Berkeley Department: Astronomy
Faculty Sponsor: Eliot Quataert

Dr. Chang's area of research is theoretical astrophysics with a particular focus on the surfaces of neutron stars. He will study various aspects of how the surfaces of neutron stars are formed and the radiation that these surfaces emit.

Joshua Eisner

Ph.D. California Institute of Technology
Berkeley Department: Astronomy
Faculty Sponsor: James Graham

Dr. Eisner's research is focused on understanding how stars and planets form, primarily through the study of protoplanetary disks around young stars. He is particularly interested in the innermost regions of these disks, where gas giants and rocky terrestrial planets may form, and he has been using the relatively new technology of near-infrared interferometry to observe these regions. In addition, he is working to try and understand the evolutionary timescales of protoplanetary disks (e.g., when do they form and how long do they last?) in order to constrain possible mechanisms by which planets may form.

Gregory Engel

Ph.D. Harvard University
Berkeley Department: Chemistry
Faculty Sponsor: Graham R. Fleming

Photosynthesis provides the fundamental energy source for life and involves some of the most reactive oxidizing agents in biology, capable of oxidizing even water. The crucial energetic steps in photosynthesis direct the energy from the absorbed photon, or exciton, to the reaction center via a rugged energetic funnel. Dynamic disorder reliably governs this flow of energy and controls the oxidation process, demonstrating an unparalleled evolutionary finesse, yet the precise mechanism of control is not well understood. Dr. Engel's research focuses on directly mapping the nonlinear polarizability with ultrafast nonlinear optical spectroscopy to understand the fundamental, dynamic coupling mechanisms that enable, direct, and control energy transfer among photosynthetic chromophores.

Raanan Fattal

Ph.D. The Hebrew University of Jerusalem
Berkeley Department: Mathematics
Faculty Sponsor: Alexandre Chorin

Dr. Fattal is interested in applied mathematics and its applications in image processing. In particular, he is developing numerical simulations for Visco-Elastic fluids based on studying their specific nature. Approximating solutions of Hyperbolic PDE's with minimal numerical diffusion and numerical linear algebra are also topics he will be working on at U.C. Berkeley. The different topics in image processing he is interested in are: wavelets analysis, texture synthesis, super resolution and dynamic range compression.

Edward Feng

Ph.D. Stanford University
Berkeley Dept: Chemical Engineering
Faculty Sponsor: Arup Chakraborty

Dr. Feng's research concerns the statistical physics of systems driven far from thermal equilibrium. Examples include polymeric and colloidal systems deformed by flow and cellular signaling switches in biology. Moreover, studying amorphous materials driven far from equilibrium may provide a means to understanding the glass transition. He seeks to understand these systems theoretically using both analytic and computational techniques.

David Jenkins

Ph.D. California Institute of Technology
Berkeley Department: Chemistry
Faculty Sponsor: Jeffrey Long

Dr. Jenkins is interested in molecular magnetic materials with the potential for data storage. Current molecular devices are often limited by the need for cryogenic temperatures. Novel approaches to synthesizing paramagnetic cluster complexes may allow us to achieve single molecule magnets at room temperature.

Jarmila Pittermann

Ph.D. University of Utah
Berkeley Department: Integrative Biology
Faculty Sponsors: Todd Dawson & Bruce Baldwin

It is generally not recognized that the Taxodiaceae family of conifers (the Coast Redwood or *Sequoia sempervirens*, and the Giant Sequoia or *Sequoiadendron giganteum*) once dominated the Paleogene (23-65 mya) forests of the Northern Hemisphere, extending as far as the once temperate arctic regions. Today's species are restricted to small, relictual populations sprinkled across California, Louisiana and Asia, inhabiting a narrow range of temperature and moisture regimes. What are the physiological features that allowed this unique group of conifers to effectively exploit their ancient habitat, and how have those features impacted their evolutionary trajectories and current distributions? Dr. Pittermann's work will aim to elucidate the evolutionary structure-function trends of the Taxodiaceae by integrating the physiology, wood anatomy, phylogeny and fossil record of this intriguing group of conifers.

Annie Tsong

Ph.D. University of California, San Francisco
Berkeley Dept: Molecular & Cell Biology
Faculty Sponsor: Michael Eisen

Increasingly sophisticated control of when and where genes are expressed is thought to be a key mechanism by which organismal complexity arises during evolution. Dr. Tsong is interested in the mechanisms by which new gene regulation arises, as well as the selective environmental pressures that shape new regulation.

Alexandra “Sasha” Turchyn

Ph.D. Harvard University
Berkeley Dept: Earth & Planetary Science
Faculty Sponsor: Don DePaolo

Dr. Turchyn's research focuses on how the chemistry of the ocean has changed over geologic time scales. During her Ph.D. she studied the biogeochemical sulfur cycle, using stable isotope geochemistry of sulfate minerals to track changes in sulfur cycle dynamics over the last 100 million years. As a Miller Fellow she will continue her study of paleoceanographic variability, focusing on understanding the geomicrobiology of sulfur cycling in organic rich sediments and a quantitative understanding of what may drive long term changes in other chemical properties of the ocean.

Feng Wang

Ph.D. Columbia University
Berkeley Department: Physics
Faculty Sponsor: Y. R. Shen

Dr. Wang is interested in probing nanostructures with photons. The focus of his work will be the optical study of individual nanostructures and its correlation to electrical and mechanical characterizations.

Awards & Honors

Arup Chakraborty (Miller Professor Spring 2000) has received the American Institute of Chemical Engineers' Professional Progress Award for Outstanding Progress in Chemical Engineering, which honors an AIChe member under the age of 45 for his or her notable accomplishments. Professor Chakraborty was honored for the application of quantum and statistical mechanics to practical problems.

Brian K. Hall (Visiting Miller Professor Spring 1997) will be honored with the 2005 Killam Prize, Canada's most distinguished annual award for outstanding career achievements in engineering, natural sciences, humanities, social sciences and health sciences. Dr. Hall will be awarded for his contributions in the field of natural sciences.

Arunava Majumdar (Miller Professor 2003-04) has been elected to the National Academy of Engineering (NAE), one of the highest professional honors for an American Engineer. Professor Majumdar was honored for his contributions to nanoscale thermal engineering and molecular nanomechanics.

Mary Power (Miller Professor Spring 2002) has received the G. Evelyn Hutchinson Award from the American Society of Limnology and Oceanography (ASLO). This award is presented to scientists who exemplify outstanding research on salt and fresh waters.

John Prausnitz (Miller Professor 1965-66, 1978-79) was awarded the National Medal of Science, the United States' highest scientific honor, for developing molecular thermodynamics for the design of separation operations in large chemical plants to make them more efficient, environmentally friendly and safe, and to reduce energy consumption.

Hans Joachim Queisser (Visiting Miller Professor Spring 1998) has been elected as an Honorary Member of The Japan Academy for his outstanding scientific contributions, including his milestone work as a semiconductor physicist.

Richard Zare (Miller Institute Advisory Board Member 1990-93) has won the annual Wolf Prize, one of the highest international awards in science and the arts, for the advanced laser techniques he has developed to analyze the details of the chemical reactions that take place at the molecular level in biology.

"Combes," continued from page 2

fly towards a scent source in the mouth of an open-air wind tunnel, even as the air velocity surpasses 7 meters per second – flying at an amazing 600 body lengths per second. Returning for a few weeks this May, Stacey hopes that orchid bees will help her further understand how flying insects use their bodies and appendages during flight. The focus this time will be on the orchid bees' bizarrely massive hindlegs. Stacey will collect more data on maximum forward flight speed and measure body drag with and without the hindlegs to determine the aerodynamic cost of hauling these legs around. She will also repeat the robotic flower trick to see how orchid bees use their hindlegs while maneuvering, and blast hovering bees with a gust of air to see if the hindlegs help or hinder bees trying to maintain stable flight in the face of environmental perturbations.

In the future, Stacey plans to perform further analyses of flight stability, most likely on local hummingbirds (which are considered honorary insects due to their flight ability). She is also interested in studying maneuvering flight during aerial predator-prey encounters, possibly between bats and their insectivorous prey. In her free time, Stacey enjoys traveling, hiking and writing, and has recently been trying to rekindle her dwindling piano-playing and Spanish-speaking skills.

The Miller Institute for Basic Research in Science invites you to celebrate 50 years of science!

December 9-10, 2005

Friday, December 9 - Alumni Gathering
Saturday, December 10 - Lunch & Dinner

Talks will be held on the following topics:

New Science at the Scale of Nanometers
Speakers: Paul Alivisatos, Matthew Francis, Hong Kun Park
Voices in Biology
Speakers: John Hulsenbeck, David Jablonski, Erin O'Shea
The Cosmology-Fundamental Physics Connection
Speakers: John Barrow, Hitoshi Murayama

To register for this event, please click on the "Register Here" link on the Miller Institute's website: http://millerinstitute.berkeley.edu

Congratulations to Miller Fellows **Munira Khalil** and **Subhadeep Gupta** on their marriage! The two were wed on April 6, 2005.

Obituaries

Morgan Harris, Miller Professor 1963-65, Emeritus Professor of Zoology, and former chair of the Department of Zoology passed away on February 14, 2005. He was 88.

Lawrence Talbot, Miller Professor 1960-61, Emeritus Professor of Mechanical Engineering known for his work in fluid mechanics, passed away on March 19, 2005. He was 79.

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Publications

The following Miller Institute members have recently published works resulting from research during their Miller Institute terms. For more information about these publications, please visit the Miller Institute's website at: http://millerinstitute.berkeley.edu/news/publications.htm

Stacey Combes
Miller Fellow, 2004-07

Eric Ford
Miller Fellow, 2003-06

Clarissa Henry
Miller Fellow, 2001-04

Nicholas Jewell
Miller Professor, Fall 2004

Ron Hoy
Visiting Miller Professor, Spring 2005

Xanthippi Markenscoff
Visiting Miller Professor, Fall 2003

Patricia Zambryski
Miller Professor, 2004-05

The Miller Institute is "dedicated to the encouragement of creative thought and the conduct of research and investigation in the field of pure science and investigation in the field of applied science in so far as such research and investigation are deemed by the Advisory Board to offer a promising approach to fundamental problems."