STANFORD MECHANICAL ENGINEERING

ME news

Summer 2012

DEPARTMENT OF MECHANICAL ENGINEERING STANFORD UNIVERSITY

Dear Alumni and Friends,

Attracting the best and brightest mechanical engineering students is the key ingredient in remaining one of the highest ranking mechanical engineering departments in the U.S. and the world. Our department is committed to bringing the best students to Stanford by providing financial support and premier laboratory facilities, as well as hiring exceptional faculty. In this issue of *ME News* we will share highlights of our recent faculty hiring efforts.

Recent Faculty Hiring

As we have mentioned in previous issues, the department has focused its energies over the past three years in identifying and hiring outstanding faculty who personify our vision for the future of mechanical engineering at Stanford. This year, we conducted two junior faculty searches to discover emerging, talented young engineers in the fields of biomechanical engineering and theoretical and computational fluid dynamics. We are currently in negotiation with the selected candidates and look forward to announcing them next year. In the meantime, we are pleased to introduce two of our newest assistant professors.

Ali Mani, who joined us in September 2011, holds a BS in mechanical engineering from Sharif University of Technology in Iran, as well as MS and PhD degrees in mechanical engineering from Stanford. Prior to his arrival last Fall, he had served as a senior postdoctoral associate in the Department of Chemical Engineering at MIT. David Lentink recently joined us in May 2012. Originally from The Netherlands, Dr. Lentink is an aerospace engineer (BSc and MSc degrees from Delft University of Technology) and an experimental zoologist (PhD from Wageningen University and Postdoc at Harvard). From 2008 – 2012, Dr. Lentink served as an assistant professor at Wageningen University. Professors Mani and Lentink have each written an article for this edition of *ME News.*

Featured Articles

David Lentink has integrated biology, engineering and design into a multidisciplinary research program to better understand the flight behavior of birds and other living things. Ultimately, Professor Lentink's ideas may inspire the design of radically different aircraft for both civilian and military transport. He describes his research and the new lab he is building at Stanford.

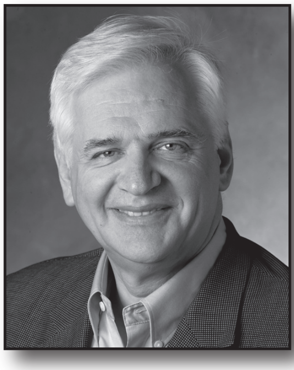
Ali Mani utilizes mathematical modeling to study the physical relationships between fluid mechanics, transport phenomena, optical and sound waves, and microscale electrokinetics. Professor Mani highlights one of his most recent studies, the generation of microbubbles via the liquid-liquid impact of breaking waves.

Ellen Kuhl's professional expertise is in the area of computational biomechanics, the creation of theoretical and computational models to predict the acute and chronic response of living biological tissue to environmental changes during development and disease progression. Professor Kuhl reports on work currently being done in her Living Matter Lab.

We recently received approval for the renovation of Buildings 520 and 524 and have been working with an architect regarding design details. Professor Ken Goodson, chair of the department planning committee, provides an update on our progress.

Finally, we would like to encourage you to read an inspiring new book, published by Professor Emeritus James Adams, which offers an in-depth look into designing quality products.

We invite you to visit our website at http://me.stanford.edu to learn about other innovative research endeavors of our faculty and students.



Fritz B. Prinz
Finmeccanica Professor and
Robert Bosch Chair

FLOW PHYSICS & COMPUTATIONAL ENGINEERING

MECHANICS & COMPUTATION

DESIGN

BIOMECHANICAL ENGINEERING

THERMOSCIENCES

Biological Flight as an Inspiration for Engineering Design

David Lentink

In spite of the fact that humans can outrun horses over long distances because of their adaptation for endurance, their swimming performance is mediocre compared to that of tuna and sailfish, and flight is impossible. So, it's no wonder that the flight of animals and plants, such as birds, bats, insects and autorotating seeds, has inspired mankind to invent its own flying machines. At just over 100 years old, human-designed aircraft have barely taken off the ground on an evolutionary timescale. Yet, recently, my colleagues and I were able to advance the field of aircraft design by producing small unmanned air vehicles at the scale of flying animals and plant seeds that innovate by mimicking nature's successful design principles for highly maneuverable and efficient flight.

In the past, engineers have provided biologists with powerful measurement techniques for fundamental research and, in return, they have given engineers biological insights for innovative design. Since I am both an aerospace engineer and an experimental zoologist, I am able to integrate biology, engineering and design into one research group. Several years ago, I started developing measurement techniques to elucidate natural mechanisms for the highly effective flight of insects, autorotating seeds, and birds. My measurements range from studying the convergent evolution of leading edge vortices generated by the wings of insects, bats and maple seeds that delay aerodynamic stall at extreme angles of attack, to the highly efficient shape-shifting wings of birds (Fig. 1).

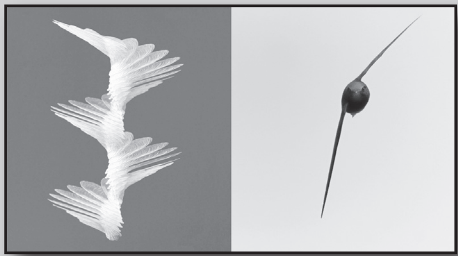


Fig. 1. Left: Autorotating maple seed. Right: Common swift morphing during flight.

Inspired by new biological insights, I have developed design strategies for innovative micro air vehicles. Together with two teams of undergraduate students, we first engineered the DelFly, a flapping micro air vehicle that can hover, fly fast, and take-off and land vertically like an insect (Fig. 2). In a subsequent undergraduate project, we developed the RoboSwift, a micro air vehicle that can morph its wings using artificial feathers inspired by the common swift *Apus apus* (Fig. 2). Common swifts are amazing birds with exquisite aerodynamic flight performance which they demonstrate as soon as they jump out of the nest for the very first time. Swifts do not land during their first year and catch insects in flight to survive. They roost at elevated heights of 5000 feet at night and even mate in the air, after which they finally land to brood. Who would not marvel over such an accomplished systems design? Modeling such a design could lead to self-healing structures for in-flight repair, in-flight energy harvesting, and the creation of extremely adaptive and energy efficient wings that enable 24/7/360 flight — a feat none of our surveillance planes have accomplished to date, big or small.

Fig. 2. Micro air vehicle "design" inspired by insect and bird flight. Left: DelFly. Right: RoboSwift.

My new research group in the Department of Mechanical Engineering will be selecting exciting biological questions, engineering new techniques to answer them, and using the results to help resolve design challenges for flying robots. Our laboratory will feature free flight space and a wind tunnel for birds that provides Stanford's engineering students, after appropriate biological training, with a unique opportunity to study bird flight as an inspiration for design (Fig. 3). In addition, our lab facilities will enable us to understand how birds fly effortlessly through cluttered and turbulent environments in which the best flying robots have failed to date. My long-term goal is to enable our engineering students to integrate biology and engineering as a tool to think "out of the box" for more effective design solutions.

Fig 3. Lovebird trained to fly in front of a high speed camera.

How Microbubbles are Generated by Breaking Waves

Ali Mani

Breaking waves contribute a great deal to air-sea gas transport as they generate tiny bubbles and entrain them below the surface of oceans. Each wave breaking phenomenon comprises bubble formation on a wide range of scales. As waves turn over and plunge, they entrap large volumes of air, which then quickly burst into big bubbles on the order of centimeters. These plunging events simultaneously contribute to vorticity generation and the development of turbulence. Turbulent eddies can deform large bubbles and fragment them into smaller pieces on the order of millimeters. As this complex process develops, microbubbles on the order of 10-100 microns are also formed.

Among this wide range of bubble sizes, microbubbles are particularly important. Even though they occupy a small portion of the total volume, they are suspended longest before they buoyantly rise to the surface. In addition, due to their large surface to volume ratio, they are quite effective in allowing gas exchange between the entrapped air and the adjacent water volume. In fact, microbubbles play a critical role in environmental phenomena such as green house gas absorption, scavenging biological surfactants, and the generation of ambient noise.

The key mechanism responsible for the generation of microbubbles is still a subject of debate. It is known that turbulence can stretch larger bubbles and fragment them into moderately small pieces. However, it has been shown that the taut surface tension found in small bubbles makes them impervious to turbulence, allowing them to maintain their spherical shape. Another mechanism under investigation is the bursting of larger bubbles on the water's surface, which is shown to leave a residue of smaller bubbles.

A third mechanism, which is the focus of this article, is the disintegration of thin air films in liquid-liquid impact events. For example, Figure 1 shows the formation of a microbubble cloud after a single drop has impacted on a water surface. Even though the mechanism connecting the impact to the microbubble cloud is not yet fully understood (and is the subject of our current investigation), a great deal of information about this phenomenon is available from experimental observation. Under favorable conditions, a single impact can generate hundreds of microbubbles, suggesting that the mechanism is extremely effective. However, experimental evidence confirms that not all impacts lead to the formation of microbubble clouds. The velocity and surface curvature must be in a certain range in order for an impact to be an effective microbubble generator.

Fig. 1. Microbubble cloud formed after a liquid-liquid impact event. The size of the impacting drop is about 5mm (Photo by ME students, Shahab Mirjalili and Lewis Marshall)

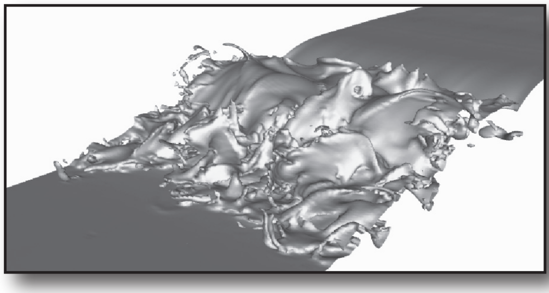


Fig. 2. High fidelity simulation of a turbulent hydraulic jump with continuous breaking events. (Simulation by ME student, Milad Mortazavi)

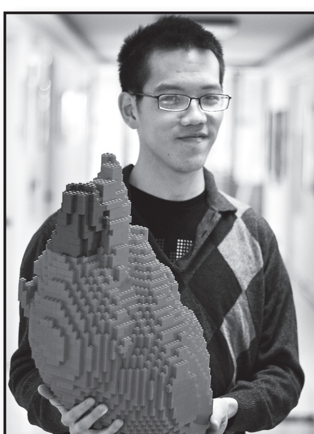
The question at hand is to determine whether liquid-liquid impact events in breaking waves are hospitable for microbubble generation. To answer this question, my research group has performed high fidelity calculations of breaking waves (Fig. 2). Our existing computer capacity allows for numerical simulations with just enough resolution to capture the events leading to the impact phenomena. Beyond that, geometrical data processing is utilized to locate instantaneous air-water interfaces and determine interface curvature and velocity in regions likely to develop liquid-liquid impacts. Our preliminary analysis indicates that these impact events in turbulent breaking waves are extremely likely to generate microbubble clouds. Although verified for only a subset of conditions thus far, we have produced the first quantitative evidence of the importance of liquid-liquid impact events in microbubble formation by breaking waves.

Simulating a Heartbeat in a Heartbeat?

Ellen Kuhl

The human heart propels more than 7,000 liters of blood throughout the body daily, beating more than 40 million times a year. It is a remarkably efficient, durable, and reliable mechanical pump, precisely regulated by spatially and temporally varying electrical and chemical fields. However, disturbed conduction and uncoordinated electrical signals can induce abnormal heart rhythms, which may critically reduce mechanical function. The past decades have generated a wealth of information to better understand the human heart. Yet, to date, there is no compelling concept to directly correlate what a basic scientist observes in the Petri dish to what a cardiologist measures in the patient.

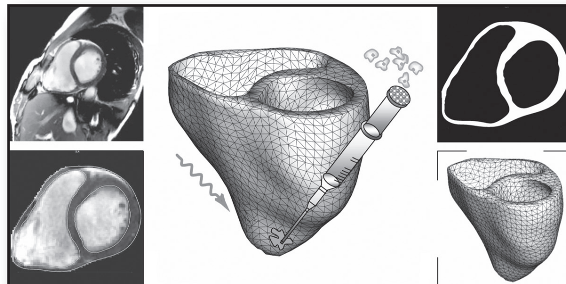
In the Living Matter Lab, we specialize in multiscale multifield mathematical modeling, a powerful concept, if not the only one, to integrate knowledge from different scales, and interrelate molecular and cellular structure to whole organ function. We have established a prognostic, physiologically mechanistic model for cardiac disease, in which alterations in form and function are correlated across four biological scales and four physical fields.



The Living Matter Lab: We build hearts.

The unique multidisciplinary nature of Stanford University offers tremendous opportunities for mechanical engineers in the quest for understanding the heart. Stanford has the largest cardiac transplantation program on the west coast, and experts from the Cardiovascular Institute, the Bioengineering Department, and the Stem Cell Institute are within close proximity. To characterize heart muscle cells on the molecular and cellular levels, we work hand in hand with the basic scientists on campus. Their data provide valuable information to calibrate our mathematical models at very small scales. To identify the characteristic features of cardiac disease on the tissue and organ levels, we closely collaborate with the clinical scientists on campus. Their patient data help us to validate our models at the larger scales. Once calibrated and validated, our models allow us to virtually probe different treatment scenarios and optimize relevant process parameters.

In a recent study, we successfully adopted this approach to virtually explore the potential of pacing human hearts with light using a new concept known as optogenetics. Optogenetics was pioneered at Stanford by Professor Karl Deisseroth and his coworkers to stimulate the brain. To explore whether optogenetics could potentially be applied to pace the human heart, Jonathan Wong, from our lab, and Oscar Abilez, from the Department of Bioengineering, have created and calibrated a multiscale multifield mathematical model of patient-specific human hearts. This model is capable of predicting the interaction of optical, chemical, electrical, and mechanical fields across different scales. It has allowed us, for example, to virtually probe different pacing sites, to quantify activation delay, and to predict required cell volumes when pacing human hearts with light.



Computer models provide insight into stem cell injection therapies and optogenetic pacing.

To guide clinical decisions, our computational models must not only be reliable and reproducible, but also robust, stable, and efficient. Ideally, our clinical collaborators want to predict the impact of their surgical manipulations in real time. With the help of Professor Eric Darve, in the Department of Mechanical Engineering, we have recently ported our algorithms to graphic card processors. This has reduced our computational time for the electrical simulation of a human heartbeat to less than ten seconds. We are excited to see how our mathematical models and computational tools are continuously moving closer to clinical applications with the ultimate goal to improve life and longevity for the millions of people who are affected by cardiac disease.

Renovation Update for Buildings 520 and 524

Photograph of the corner of building 524 and adjacent building 520, which will be extensively renovated for faculty and student offices and undergraduate teaching.

The Mechanical Engineering Department benefits from its location near the heart of the traditional Stanford campus and the university's commitment to renovating traditional buildings to meet the modern needs for research and teaching. The past year has brought much progress on planning for the renovation of buildings 520 and 524, which involves a complete rethinking of the interior architecture and provides space for faculty and student offices and undergraduate teaching. Building 520 is the home of our Thermosciences Group and Building 524 was the former location of the Civil Engineering Fluid Mechanics Laboratory, newly reassigned to Mechanical Engineering. The department planning committee and the university are working with Chris Wasney, the architect responsible for the impressive Peterson Building (550) along the same corridor. The designs are taking shape nicely with generous lighting for both the student teaching spaces and the faculty and student offices. Although these buildings will experience a dramatic transformation from within, the exterior will remain consistent with the general architecture at the heart of campus. We look forward to the continued support from our alumni and friends to realize the transformation of this part of the campus.

In Memoriam, Elliott Levinthal (1922 – 2012)

Professor Elliott Levinthal died of natural causes on January 14, 2012 at his home in Palo Alto. He was 89.

Professor Levinthal graduated from Columbia in 1942, received a master's degree from MIT in 1943 and a PhD from Stanford in 1949. After completing his doctorate, Professor Levinthal joined Varian Associates as one of the founding employees, rising to serve as research director and, ultimately, as a director of the company. In 1953, he founded his own company, Levinthal Electronics Products, which developed some of the first defibrillators, pacemakers and cardiac monitors. In 1961, he joined the Genetics Department of the Stanford School of Medicine, where he worked with Joshua Lederberg on exobiology, examining the question of extra-terrestrial life and designing experimental missions to Mars. At the medical school, he became a research professor and director of the Instrumentation Research Laboratory. The laboratory was active in the design and operation of mass spectrometers and their computer control and analysis.

After a three-year leave from Stanford, serving as director at the Defense Advanced Research Projects Agency (DARPA), he became a research professor in the Department of Mechanical Engineering and director of the Stanford Institute for Manufacturing and Automation (SIMA). He later became associate dean of research at the School of Engineering.

In addition to his academic roles, Professor Levinthal was active in the development of a number of Silicon Valley companies and was a generous philanthropist. He provided financial support to less advantaged students to attend Stanford and was a supporter of the humanities. His philanthropy included the establishment of the Levinthal Tutorials program in creative writing at Stanford.

From the Stanford Report

Book Review: "Good Products, Bad Products" (by James L. Adams)

Emeritus Professor Jim Adams, author of *Conceptual Blockbusting*, recently published a provocative new book entitled, *Good Products, Bad Products: Essential Elements to Achieving Superior Quality* (McGraw Hill, 2011) based on his popular ME 314 class of the same name. Jim's book provides an in-depth look at the essential but elusive qualities that can make or break a product's success, ranging from seemingly straight forward topics such as human fit and craftsmanship, through emotional responses to such things as aesthetics, elegance, sophistication, cultural fit and, finally, global fit. As James Plummer, Dean of Stanford's School of Engineering, says in his endorsement, "...it should be required reading for every engineering student interested in designing great products... Every aspiring engineer wants to have an impact and this book will absolutely help. Read it!" We hope you will.

ME *faculty achievements*

David M. Barnett
A. C. Eringen Medal from the Society of Engineering Science (SES), October 2012.

Mark R. Cutkosky
Fellow of the Institute of Electrical and Electronics Engineers (IEEE), 2012.

Wei Cai
Vance D. and Arlene C. Coffman Faculty Scholar Award, Stanford University, 2011.

Scott L. Delp
Fellow of the American Society of Biomechanics (ASB), 2012.

Charbel Farhat
Knighted by the Prime Minister of France in the Order of Academic Palms and awarded the Medal of Chevalier dans l'Ordre des Palmes Academiques, November 2011.

International Association for Computational Mechanics (IACM) Award, July 2012.

Kenneth E. Goodson
Fellow of the American Society of Mechanical Engineers (ASME), 2012.

Ronald K. Hanson
2011 American Institute of Aeronautics and Astronautics (AIAA) Best Paper in Propellants and Combustion, April 2012.

Most-Cited Paper Award from *Combustion and Flame*, March 2012.

R. I. Soloukhin Award from the Institute for the Dynamics of Explosions and Reactive Systems (IDERS), July 2011.

Thomas W. Kenny
Institute of Electrical and Electronics Engineers (IEEE) Sensors Council Technical Achievement Award, October 2011.

Sanjiva K. Lele
American Institute of Aeronautics and Astronautics (AIAA) Fluids Dynamics Best Paper Award, June 2012.

Adrian J. Lew
International Association of Computational Mechanics (IACM) Young Investigator Award, July 2012.

Parviz Moin
Elected to the National Academy of Sciences (NAS), May 2011.

Bernard Roth
American Society of Mechanical Engineers (ASME) Mechatronic and Embedded Systems and Applications (MESA) Achievement Award, August 2011.

Institute of Electrical and Electronics Engineers (IEEE) Robotics and Automation Award, May 2012.

Thomas Egleston Medal for Distinguished Engineering Achievement, the highest honor given to alumni by the Columbia Engineering Alumni Association, May 2012.

Sheri D. Sheppard
American Society of Engineering Education (ASEE) Ralph Coats Roe Award, 2012.

ME News is published by the Department of Mechanical Engineering, School of Engineering, Stanford University.
Editor: Deborah Sutherland Visit our website at http://me.stanford.edu