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AEM Update

Department of Aerospace Engineering and Mechanics

Winter 2009

Flow Structure Interaction

The changing face of fluid mechanics fundamentals

Imagine a submarine with a dolphin-like soft skin being pursued by an enemy sub. With a moment's notice, the skin comes alive and morphs to generate a micrometer scale wavy surface deformation, the submarine suddenly makes a silent sharp turn at high speed and slips away into the depths without a trace. This is the primary research in Flow Structure Interaction of new AEM faculty member Jian Sheng, and is one application of many he hopes to discover.

Flow structure interaction is a fundamental yet common problem in fluid mechanics and has many over-arching implications. The interactions between the flows and the solid structures are often coupled and complex. The change in the structures is initially caused by the viscous force exerted by the moving fluids. Consequently, this changes the flow by altering the boundary conditions.

"Very few theoretical and computational investigations encompass the entirety of the problem without some form of simplification," comments Sheng.

Sheng and his team are employing several novel experimental approaches to investigate these coupling mechanisms, one of which involves simultaneously

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Gary Balas, Department Head

Chairman's Corner

Friends and colleagues,

We are in the midst of "Spring" semester, though it's hard to call it "spring" with another winter storm bearing down on us. But, the end of the school year is just ahead of us.

The fall and spring have been full of success for our faculty and students, and we take great pride in the awards they receive. This year, Graham Candler has been selected from over 650 nominations as one of six 2009 National Security Science and Engineering Fellows. Ryan Elliott was selected as a McKnight Land-Grant Professor. Our faculty have received nine of these Professorships since the program was established in 1987, a number surpassed by only two other departments at the University.

As we move forward, renovation of the Akerman Hall hangar remains a top priority for us. This past fall we received funding from the University to renovate the three first floor laboratories as part of the lab renovation program made possible with funding from the last State legislative session. In what we consider to be the first phase of the planned total renovation of the hangar, the initial architectural design is currently in process.

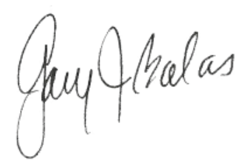
The completed hangar will provide a grand entrance to Akerman Hall, address building life and safety issues, greatly improve undergraduate and graduate laboratories and add research office space.

Finally, the financial crisis facing the state of Minnesota will likely result in a significant cut to University's budget from the legislature. While the final budget has not yet been set, we are being asked to plan for a 6% to 9% reduction in our base budget for the next academic year and no salary increases for our faculty and staff.

We will continue to do all we can to minimize the effect of these cuts on our students but the projected size will obviously have an impact on students, staff and faculty.

I will keep our constituents informed as more information is made available.

In closing, I would like to take the opportunity to thank all of you who generously donated your time and money to support the AEM department. You're contributions have helped us provide an outstanding education for our students and we very much appreciate it.



Around the Department

Faculty news and department happenings

Prof. Richard D. James was awarded two esteemed research awards, the William Prager Medal from Society of Engineering Science, and the Warner T. Koiter Medal from the American Society for Mechanical Engineers. These awards were presented at the society's events in November. | *Prof. Graham Candler* was selected as one of six 2009 National Security Science and Engineering Fellows. He was selected from over 600 faculty across the country. | *Prof. Roger Fosdick* presented the Truesdell Lecture at the 47th meeting of the Society for Natural Philosophy at the University of Pittsburgh in September. The title of his talk was "Continuum Thermodynamics from the Perspective of Invariance." | *Prof. Daniel D. Joseph* presented "Lubricated Pipelining -- Natures Gift." as the Sir James Lighthill Distringuished Lectureship at Florida State University. | The department congratulates the following graduate program Masters graduates: Christopher Alba, Vladymir, Gidzak, Nuri Kundak, Stephen Levin-Stankevich, Matthew Rinehart, Shervin Shajiee, Guijin Zheng. | Dr. Shankar Ghosh completed his doctoral degree. He successfully defended his thesis: "Direct Numerical Simulation of the Interaction of a Laser induced Plasma with Isotropic Tubulence" under the guidance of Prof. Krishnan Mahesh. Ghosh will continue his work with Mahesh as post-doctoral associate. | Under the advisement of Prof. Gary Balas, Dr. Balint Vanek defended his thesis entitled: " Control methods for High Speed Supercavitating Vehicles" which concluded his doctoral work. Vanek is currently working for Honeywell International in Bruno, Czech Republic, as a lead flight control engineer. | Dr. Haoping Yang defended his thesis " Topics in the Flow of Fluids in Pipes." to complete his PhD under adivsor Prof. Daniel D. Joseph. Yang is now working as a post doctoral researcher at University of Miami. ◊

Decoding Spatial Behavior

Mettler examines how humans achieve their unique piloting skills

Humans are highly capable in spatial control tasks, whether it involves their own body or operating a vehicle. For example, maneuvering a helicopter: under ideal conditions humans can operate at the physical limits of the vehicle; in poor conditions, we adapt to ensure safe operation. Professor Bernard Mettler, who joined the department in 2006, current research is examining how the human brain learns these unique skills.

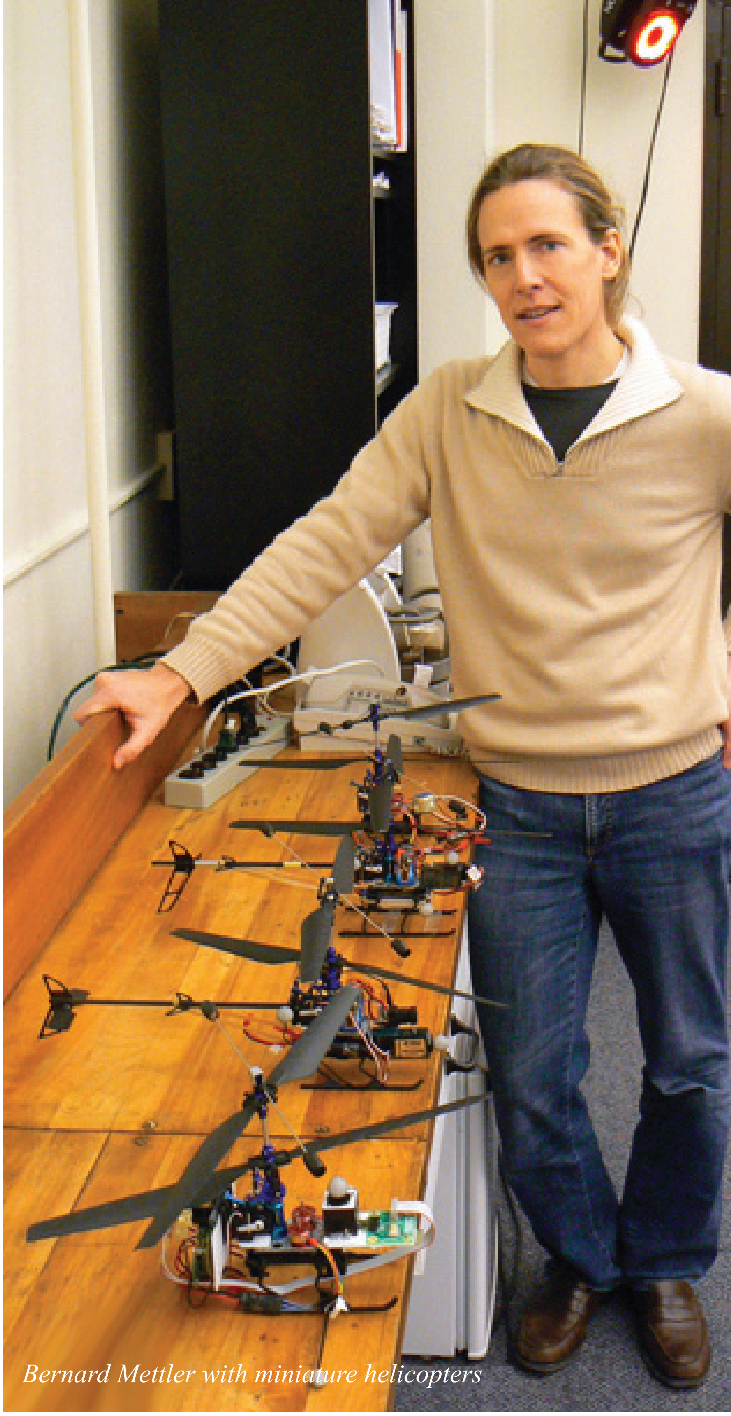
From a control theoretic standpoint, determining the trajectories to guide the vehicle in real time, under partial knowledge is a very complex problem. “Considering the underlying neurological processes, the brain’s performance in these complex tasks raises several fundamental questions,” commented Mettler. How is spatial information represented? How is the control behavior generated? How are the dynamics taken into account? How are the inevitable unknowns factored into decisions?

Current and previous work on motor control covers a range of behaviors including arm, posture, or eye motion. Research on spatial behavior has mostly focused on spatial representations and navigation, though little research has been devoted to the type of dynamical and higher-dimensional control problems that piloting an aircraft represents.

Mettler states that helicopters are ideal tools to investigate human control strategies involving fast motions in complex spatial environments. “Helicopters are highly maneuverable vehicles that can move freely in all three dimensions, yet their dynamics are not trivial and humans still surpass autonomous control algorithms.”

To study a pilot’s dynamic spatial control skills Mettler, and his team set up an experimental facility that allows the recording of human control behavior of a miniature helicopter in a variety of spatial control tasks.

A first set of experiments were performed with a target directed acquisition task; the human subject controls the helicopter to a defined goal. Alogrithms developed by the group were used to analyze the spatial control performance from an ensemble of recorded trajectories. Trajectories are converted to a vector field that describe the vehicle dynamics in terms of spatial distributions of their state. Such a state vector field is known in optimal control as a field of extremal, or a value function. It encodes the vehicle dynamic as a function of space. This represents a map of the vehicle behavior.


Bernard Mettler with miniature helicopters

To characterize the brain processes involved in these dynamic spatial control skills Mettler plans to identify the particular control realization that produces similar state vector fields. The solution to this problem is not unique; different control realizations will likely produce the same field. The working hypothesis is that the control process involves a combination of predictive control and some approximate representation of the vector field. This approximate vector field provides global knowledge and is what the pilot learns when performing a task. The online prediction used to determine the pilot behavior makes up for partial knowledge and disturbed conditions.

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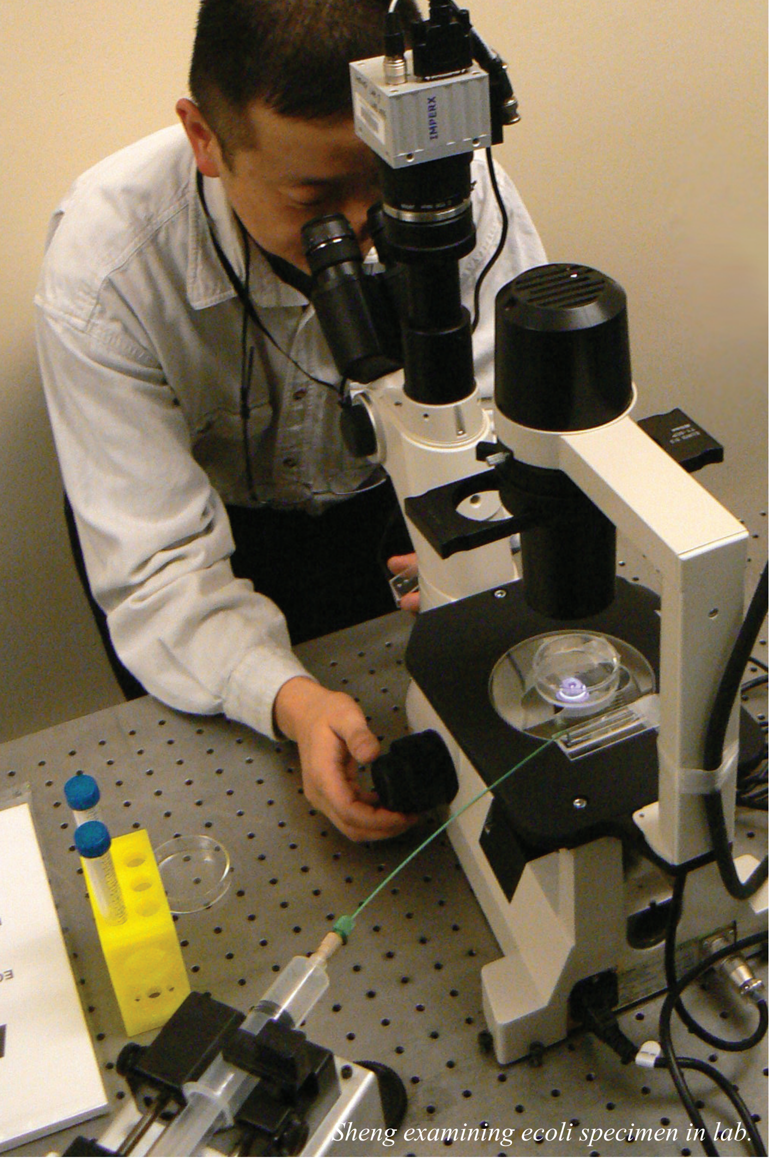


Sheng examining ecoli specimen in lab.

...Sheng continued

measuring the 3D structure deformation and at the same time the 3-D fluid flow motions. In observations, these methods emphasize three-dimensionality and simultaneity as well as high measurement resolutions (often down to a hundred nanometers) leading to more accurate observations.

"The primary technique employed in my research is digital holographic microscopy (DHM) which expands the depth of field of a conventional microscope by at least 1000 times while maintaining equitable lateral spatial resolutions over the entire measurement volume, like a three-dimensional microscope," notes Sheng. While the technique is equally powerful and revolutionary at much larger scales, the term "microscope/microscopy" is used loosely to describe the technique's unique ability in providing 3-D high-resolution observations at microscopic scales.

The other novel investigation tool utilized is environmental microfluidics, which is the use of a microscopic device with the size of 100μm, upon which they exquisitely manipulate the local mechanical and chemical properties, such as flow shear, temperature, chemical composition on surface roughness.

Combined with DHM, the microfluidics provide an ideal platform to study small-scale cell wall interactions at both individual level and population scale. With this technology, Sheng's group is able to track a collection of particles simultaneously while resolving nanometer structures on each individual particle in 3-D space.

With recent funding from an NSF Career Award, NIH and support from the University, this work is advancing in three directions. The first is the development of next generation experimental techniques. Sheng projects the use of multi-dimensional, multi-component techniques including 3-D fluorescence microscopes, x-ray digital holography, PIV (Particle Image Velocimetry), and 3-D flow accelerometer.

Secondly, Sheng is studying the interactions between arteries and their flows, with emphasis on the coupling mechanisms between wall deformation and near wall flow structures. "We are investigating two conditions: non-compliant vs homogeneous compliant and homogeneous vs inhomogeneous compliant (e.g. healthy artery vs the one with plaque)," said Sheng. The implications of the interaction on cell migration will also be investigated directly with artificial red blood cells.

Finally, using microfluidics and DHM, Sheng's group plans to study the biofilm formation under a sheared environment and irrigation within a fully developed biofilm. "We plan to directly monitor cell detachment and attachment processes during the initial formation," comments Sheng. This will also provide first hand observations on the mechanisms governing nutrient transport and antibiotic resistance within a fully developed biofilm.

In the long-run, Sheng's group will advance the understanding of dynamical processes involved in various flow and deforming surface interactions with a strong emphasis on bio-related or bio-inspired flow structure interactions.

For more information on Prof. Jian Sheng and his work, visit our webpage at www.aem.umn.edu/jsheng.

The Next Generation

Student Profile: Venkata Guthikonda, AEM Graduate Student


Venkata Guthikonda

Venkata Suresh Reddy Guthikonda began showing promise a few weeks into his first semester in the Fall of 2005 with his already high level of understanding and intelligent questions. After joining the ranks of Prof. Ryan Elliott's research group, Guthikonda began work to develop a new methodology for modeling "active materials" from the atomic level; these are materials that possess the uncommon ability to significantly change their properties such as shape, color, hardness in response to external stimulus. Such as materials used in medical devices, electronic ignition devices, ink-jet printers, accelerometers and data storage devices similar to those used in iPhones and iPods.

Guthikonda and Elliott are working together to develop the next generation of "fatigue resistant" Shape Memory Alloy (SMA) materials through computational modeling techniques. SMAs are intelligent materials that have an amazing ability to crumple, bend and generally undergo large deformations in response to applied load, then immediately recover their initial shape when the load is removed, behavior otherwise known as "pseudoelasticity."

Additionally, Guthikonda's current research examines the effects of temperature on SMA materials, for example their ability to hold a deformed shape or return to the original shape based on the material's temperature. Because of these remarkable abilities, the use of SMAs in medical devices and instruments is a rapidly growing multi-billion dollar industry.

The results of Guthikonda's research and further explanation were discussed in his masters thesis, and subsequently published August 2008 issue of the *Journal of Elasticity.* ◊

Alumni Profile

Alums contibute to NASA Mars Phoenix mission

The Mars Phoenix lander arrived on the Red Planet in May 2008 after a successful launch in August of 2007. Phoenix then survived for five months on the planet, transmitting back telemetry and more than 25,000 images of the planet before succumbing to the harsh Martian winter.

In an article posted on Times Online, NASA's head of the mission, Doug McCuiston made it clear that the Phoenix made important discoveries during its operational life on Mars including the presence of ice under the planet's surface as well as the presence of salts that could comprise nutrients necessary for life.

AEM alums Jim Chase, Scott Doudrick and Maria Schellpfeffer participated directly in all phases of the exploration mission. This mission began August 2003 when it was selected by NASA for launch.


Alums with Mars Phoenix Lander Model
Left to right: Jim Chase, Maria Schellpfeffer, and Scott Doudrick

Doudrick (MS 1997) acted as the Phoenix Payload System Engineer beginning 2004. He was key in developing the Payload Test area and delivered inter-payload cabling and Payload Electronics Boxes.

Chase (BS 1999) participated as a systems engineer in the project. He contributed to entry, descent, and landing (EDL) and surface operations. As part of EDL, he also helped lead the simulation team for modeling and fine-tuning the spacecraft performance.

Schellpfeffer (BS 2003) worked on the development of the background sequence generation software pre-launch and led the sequencing operations during the cruise and approach phases. During the surface phase she integrated and modeled the science sequence products that are uplinked to the spacecraft each day.

Chase commented, "We are proud of our U affiliation and … the mission's success reflects well upon the U." ◊

Turbulent Jets in Cross-flow

A look at of Krishnan Mahesh's research in cross flow

AEM faculty Krishnan Mahesh works on the computation, analysis, and modeling of turbulent flows. His research focuses on fundamental advances in numerical algorithms, turbulence models and understanding of flow physics that allow the prediction of engineering turbulent flows. Such techniques have traditionally been restricted to fairly simple, academic flows.

Mahesh's research is developing the capability to perform such simulations in complex engineering configurations. "We conduct research on applications from marine propulsor flows to hypersonic transition and scramjet flows, turbulent reacting flows in combustors, and flows involving plasmas," says Mahesh. The example in the figure below is a large-eddy simulation of the flow inside the combustor of an aircraft gas turbine engine.

Currently his group is working on methods to actively control jets in crossflow. The term, 'jet in cross-flow' refers to a jet of fluid that exits an orifice to interact with the surrounding fluid that is flowing across it.

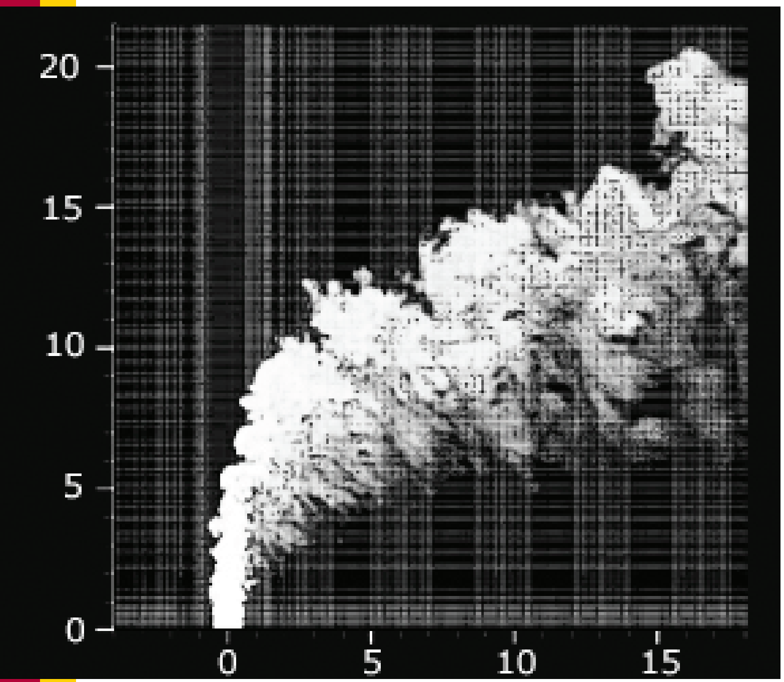
"Jets in cross-flow are central to a variety of important applications including dilution holes in gas-turbine combustors, fuel injectors, and pollutant dispersion from smoke stacks," Mahesh comments.

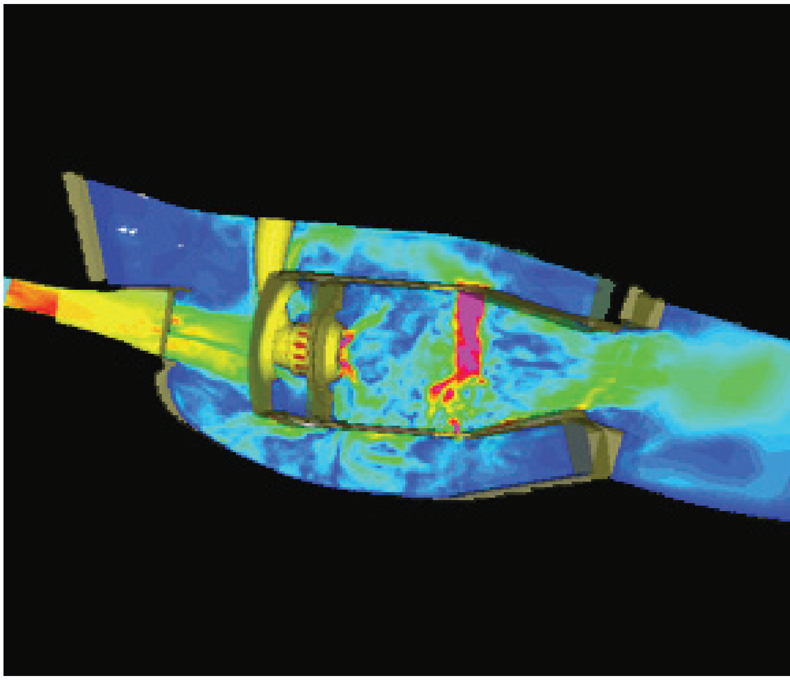
In gas-turbine combustors, jets of air enter the combustion chamber through the dilution holes, and mix with the cross-flow inside the combustor. These dilution jets cool the combustion products and leads to a reduction in pollutants. The objective of this work is to develop jet pulsing as a strategy to enhance its mixing with the crossflow.

Simulations by PhD student Rajes Sau study how pulsing the jet affects trajectory and mixing. The work recognizes that pulsing produces vortex rings and also that the behavior of pulsed jets can be explained by considering the behavior of individual vortex rings.

Mahesh comments, "A key result has been the discovery of three distinct flow regimes with distinctly different mixing characteristics." His group has also found that experimental results for pulsed transverse jets correlate very well with the boundaries between these regimes. Optimal control parameters such as pulsing frequency and duty cycle can then be determined from the regime map developed by this work.

Future research will consider surrogate optimization and alternative methods of actuation. The techniques being developed will enhance the mixing of single jets and will then be applied to control dilution jets in gas turbine combustors. Mahesh concludes, "Our long-term vision is to develop a new generation of 'clean' combustors, without compromising efficiency." ◊





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...Mettler continued.

From a control theoretic standpoint, this architecture is attractive because it represents a formal framework to study complex human control behavior. “In particular, it allows quantifying notions such as skills and a priori knowledge of a task and to explain their overall effect on control performance,” stated Mettler.

From a biological standpoint, such a model is attractive because it provides a platform to decode brain activity data and discover how the brain actually implements the functions responsible for the unique human control skills. ◊