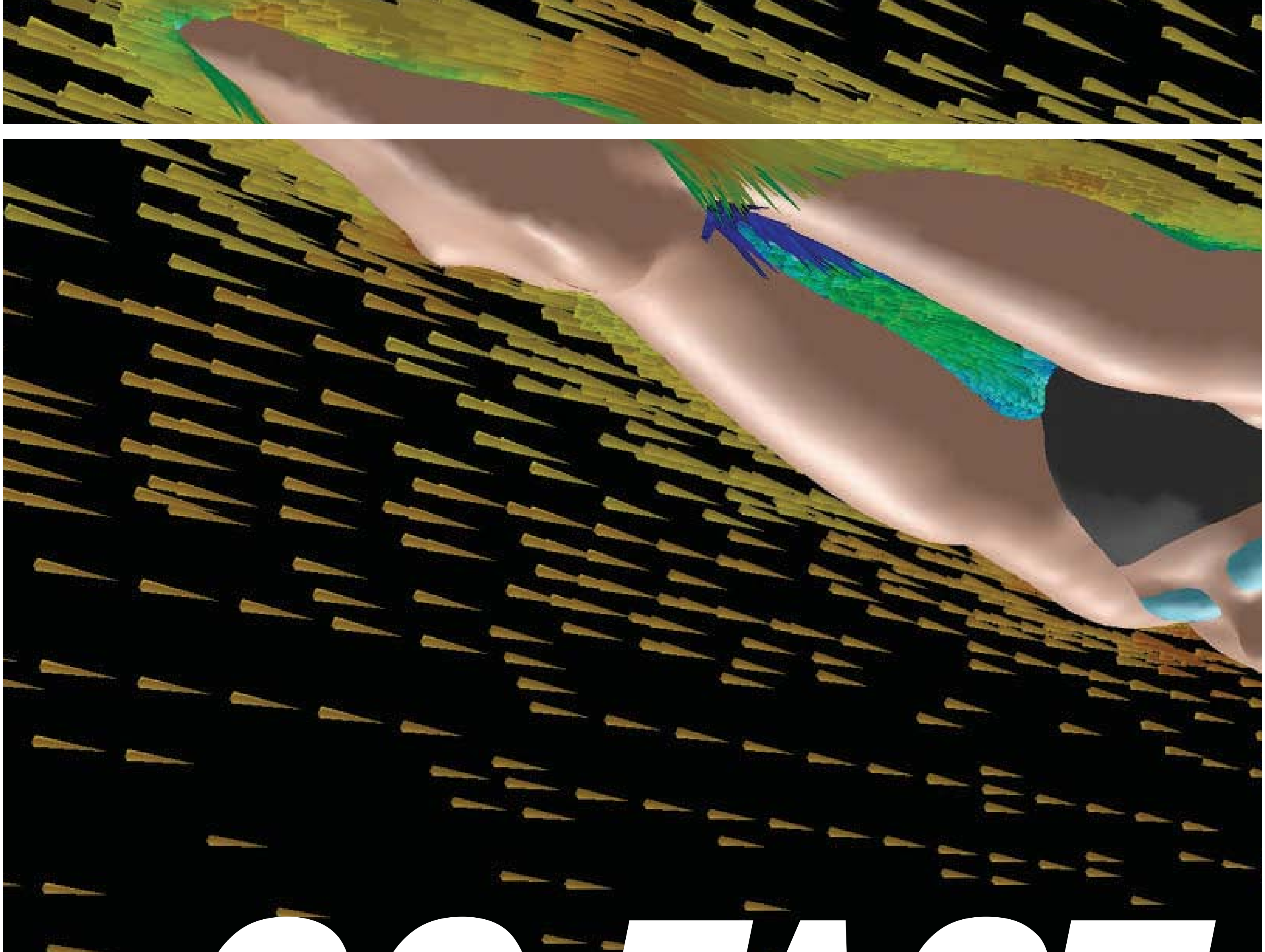
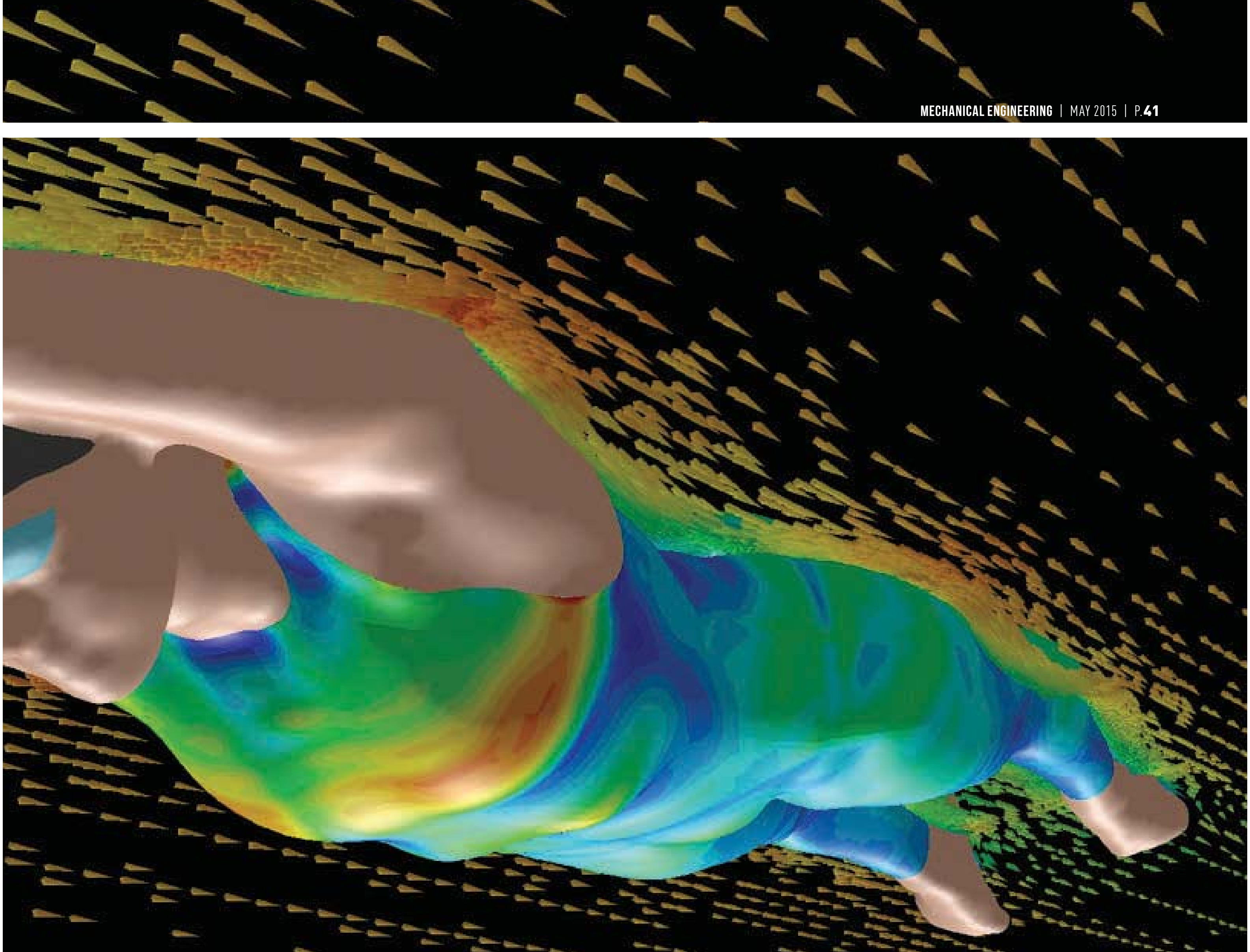


GO FAST WITH THE FLOW

COMPUTATIONAL FLUID DYNAMICS MAKES SENSE OF WAVES IN SWIMMING.

BY JOHN MARTIN



VERTEBRATES CLIMBED OUT OF THE WATER AND ONTO LAND SOME 350 MILLION YEARS AGO, BUT WE STILL LIKE TO JUMP BACK IN AND RACE AROUND LIKE THE OLD DAYS. And when we race, we want to go as fast as we can. Elite swimmers have turned to computational fluid dynamics—solving complex equations to predict how water will flow under different situations—to feed their need for speed.

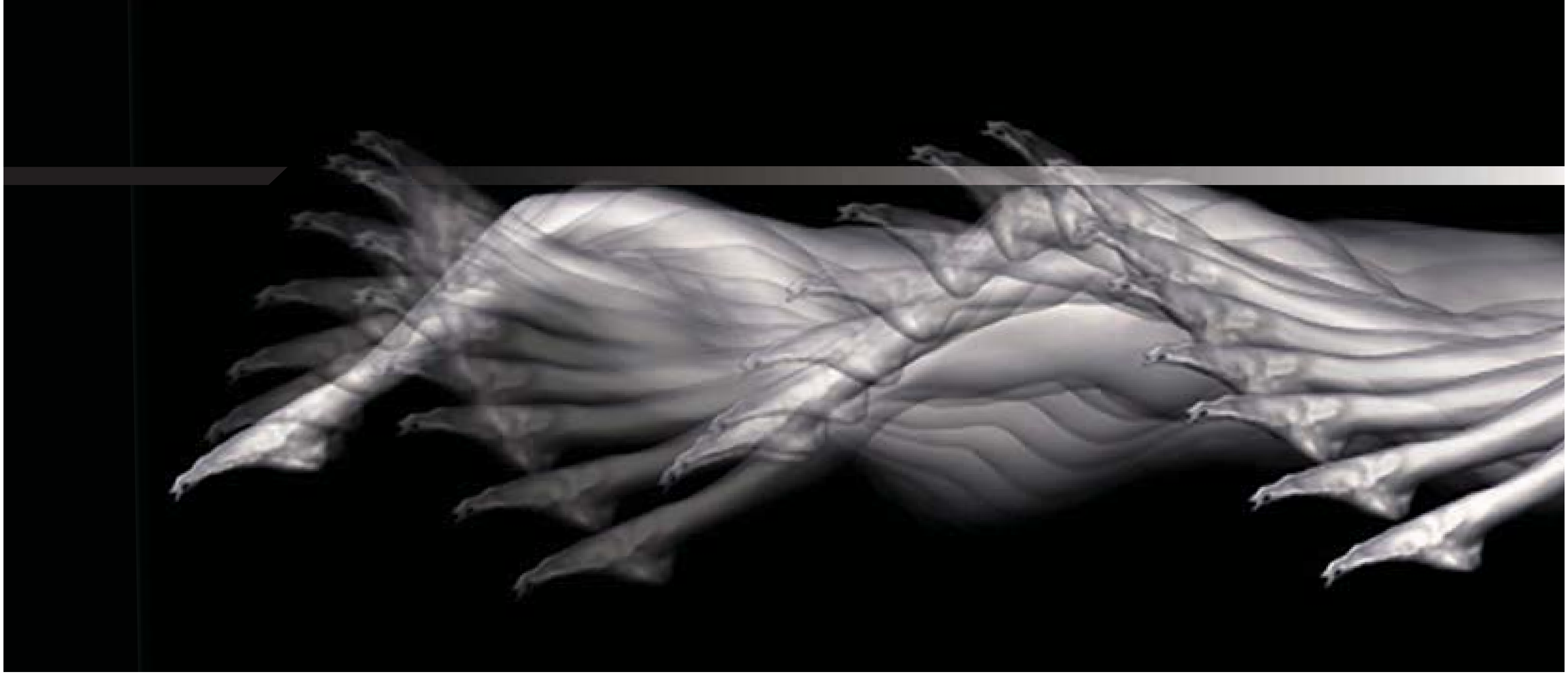
The goal is to go faster by reducing drag.

"Drag is due to the friction between the water and the swimmer that induces a force to slow down the swimmer," said Thierry Marchal, industry director for the sport industry at ANSYS Inc. "The intent is to model the water surrounding the swimmer and identify which parts of the body generate the largest drag."

Early work was done in the mid-1990s by the late Barry Bixler, an aeronautical engineer at Honeywell Aerospace who analyzed air flow in jet engines. When his daughter took up swimming as a sport, the engineer—ever the tinkerer—began looking at how swimmers move through the water.

"Bixler's initial investigations into CFD and swimming used a disk of the same size as a human hand to estimate the forces on the hand throughout the freestyle swimming stroke," said Andrew Lyttle, lead biomechanist for technical sports at the Western Australian Institute of Sport. "With improved technology, this was adjusted to create a model of the hand and forearm which optimized pitch angle of the hand in the water. These studies

Competitive swim teams are using computer models, like this one from ANSYS, to gain insights that will shave fractions of seconds from race times.
Image: ANSYS



A computer image of the dolphin kick combines 3-D scans of two swimmers performing the kick underwater. *Image: Tina Ma and James Hahn, George Washington University*

utilized the growing capabilities of the commercial software Fluent to estimate the effects."

Russell Mark joined USA Swimming—the national governing body for the sport of swimming in the United States—in 2002. The University of Virginia breaststroker had been working as an aerospace engineer at Pratt & Whitney on an experimental military engine program but left to pursue his passion for swimming. He picked up CFD investigations that had been done by Bixler in collaboration with Scott Riewald, a USA Swimming biomechanist.

Mark began working with a team led by Rajat Mittal at George Washington University. Mittal is now professor of mechanical engineering at the Whiting School of Engineering at Johns Hopkins University.

"We used their custom CFD code to study flow around a dolphin kick and the arm stroke of a freestyle and backstroke pull," Mark said. "We were able to visualize the vortices in dolphin kicking and confirm that ankle flexibility is a hugely important factor in developing those thrust-producing vortices. We were also able to confirm that an arm stroke in backstroke and freestyle that applies force directly against the water in a backwards direction is the best stroke."

USA Swimming created laser scans of Olympic-level swimmers and underwater videos of swimmers' strokes. Mittal's team merged these to create animated 3-D models of the swimmer by using MAYA, the software used to create animated movies such as *Shrek*.

"The models are input to our in-house CFD code ViCar3D," Mittal said. "The simulations are done on large-scale parallel computers." (ViCar3D stands for "viscous incompressible Cartesian grid solver in 3-D.")

Previous methods used to analyze a swim stroke required expensive and time-consuming physical simulations using wind tunnels and specially constructed pools. Now, if experimental confirmation is needed, "CFD can inform these tests by suggesting critical locations for probes, reducing the costly, lengthy physical testing to a primary model validation task," Marchal says.

The CFD emphasis is virtual. According to Lyttle, "Using known physics and fluid dynamics relationships, CFD allows complex fluid flow regimes and geometry to be simulated within a computer environment. The ability to obtain segment-specific fluid force data within a full-body stroking model provides enormous amounts of information that would be unobtainable via current empirical testing techniques."

CFD software imports a realistic geometry of the athlete, generates the geometry of the surrounding water and air, and meshes these geometries to represent the athlete's body in its surroundings. Meshing creates large numbers of small boxes—cells—around the athlete as the framework to solve millions of equations describing the water flow. Engineers analyze the results by using visualizations of the flow pattern for regions of high drag.

"In CFD, experiments are conducted in a virtual environment with a biomechanical model of the swimmer in a computational model of the pool," said Raymond Cohen, research scientist in computational informatics at the Commonwealth Scientific and Industrial Research Organisation, Australia's national science agency. He delivered the idea in a paper, "Computational fluid dynamics as a tool for improving stroke technique," at the XIIth International Symposium on Biomechanics and Medicine in Swimming held last year in Canberra.

"Individual aspects of stroke can be modified in isolation, providing a controlled and repeatable testing environment," Cohen wrote. "The

LZR ZAPPED

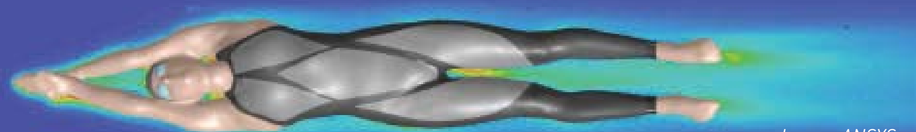


Image: ANSYS

Bondi Beach has the reputation as a laid back place for fun in the sun, sand, and surf. The Sydney suburb is also the birthplace of Speedo, a relentless innovator in swimwear. Speedo introduced the first non-wool suit in 1928—allowing greater freedom of motion—as well as the first nylon suit, the first chlorine-resistant fabric, and even a swimsuit inspired by shark's skin.

Speedo used computational fluid dynamics to develop its Fastskin FSII swimsuit prior to the 2004 Athens Olympics. In February 2008 it took engineering assist to another level with the launch of its LZR Racer, a full-body suit, ahead of the Beijing games. In ten weeks, swimmers wearing the suit had set 35 world records. Michael Phelps won eight gold medals in Beijing wearing the suit; athletes wearing Speedo won some 90 percent of the swim medals.

Speedo used Fluent from ANSYS Inc. for the CFD analysis. The research was spearheaded by Aqualab, Speedo's in-house R&D group, and included academic and industry partners, even NASA.

The CFD studies focused on passive drag, when the swimmer is in the glide position. When swimmers dive into the pool they hold this position—arms outstretched in front, legs stretched out in back—for up to 15 meters after diving, and after kicking off the pool wall under water at each turn. That's 30 percent of a 100-meter sprint across a 50-meter long-course pool—in a race that might be decided by one-hundredth of a second.

The CFD data helped researchers design the suit to lower skin drag, especially the siting points for the low-drag, polyurethane membrane panels that are bonded onto the suit. These panels reduced skin drag by 24 percent vs. Speedo's previous fabric.

It was too good to be legal. FINA—Fédération Internationale de Natation, the world governing body for swimming—banned the LZR Racer, and all full-body suits, in 2010.

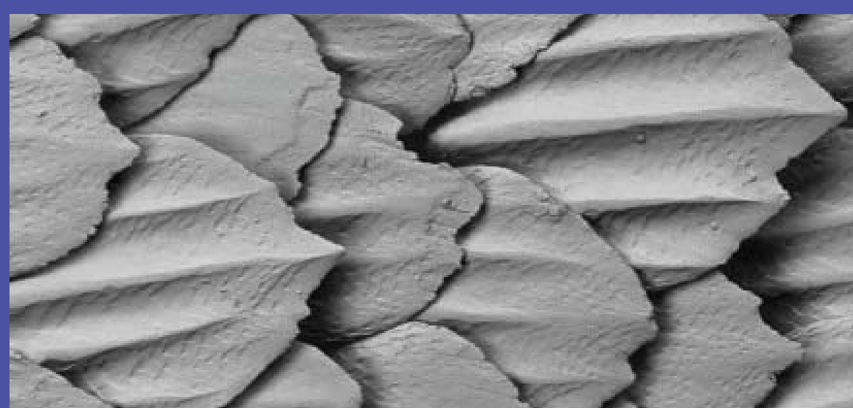


Image: Trevor Sewell/Electron Microscope Unit, University of Cape Town

A shark's dermal denticles, which decrease drag and turbulence, inspired the record-setting LZR Racer swimsuit (above), which was eventually banned from competition.

resulting performance changes can be analyzed and the underlying physical mechanisms can be explained. The results are then fed back to the coaches to help inform further testing of stroke technique."

For example, when Matt Keys, a CFD consultant with a joint appointment at the Western Australian Institute of Sport and the University of Western Australia, used a CFD model of the underwater dolphin kick, he found that a 10-degree increase in ankle plantar flexion—the ability to fully extend the foot, pointing the toes along the long axis of the body—created 16 newtons greater peak propulsive force by the feet during the kick downsweep.

According to Lyttle at the Western Australian Institute of Sport, "This provides important information to coaches on the potential beneficial effects of greater ankle flexibility for generating propulsion while kicking underwater."

BACK TO NATURE

Swimmers who want to swim like the fishes also have to overcome "outerwear" differences between themselves and their full-time aquatic

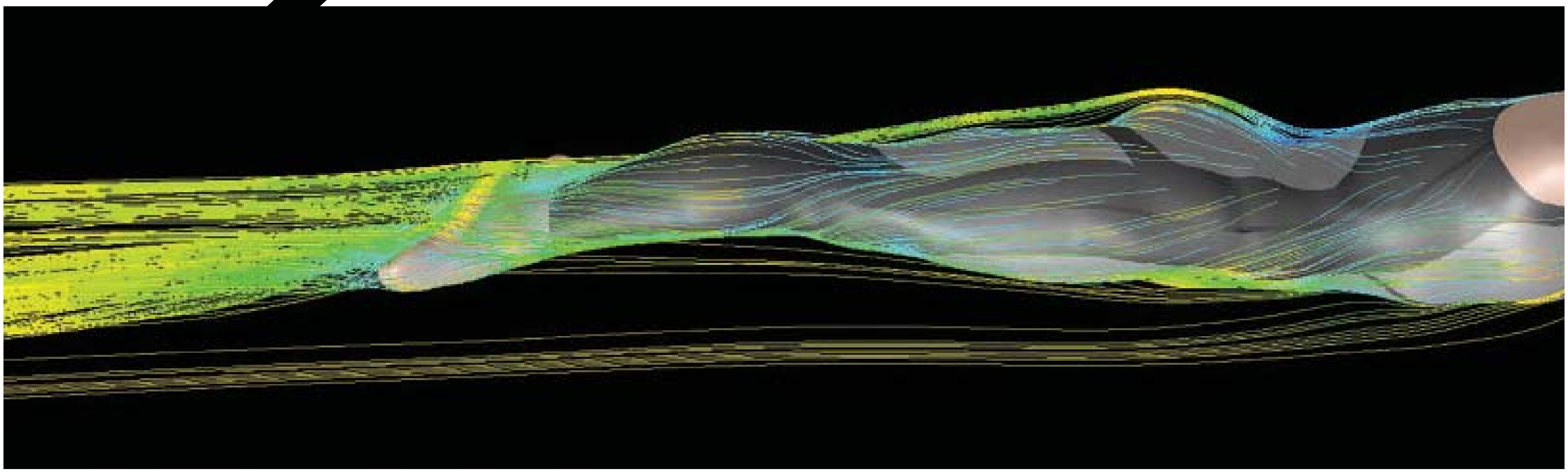


Image: ANSYS

brethren, said Frank Fish, professor of biology at West Chester University in Pennsylvania, in a presentation to the 2014 Biomechanics and Medicine in Swimming symposium. "The skin of marine animals is tighter than the integument of humans. The pliability of human skin produces mobile skin folds that add to drag," Fish said in his presentation, "Limitations on swimming speed: How can natural technologies be utilized?"

Bixler, the pioneer in all this, turned his attention from swim strokes to swimsuits and eventually became a consultant to Speedo. He helped design a suit that minimized the time water particles remained in contact with the swimmer's body—via ridges that shooed away water and lessened drag. This was used in the Speedo Fastskin FSII swimsuit and is likened to a shark's skin, which has ridges called denticles. Bixler was cited as contributing to one of "America's 100 Best Innovations" for 2004.

Speedo went on to leverage CFD in designing its LZR Racer, a suit so fast in the water that it was banned, and continues to use computational fluid dynamics to model the overall swim "system," which includes the suit, cap, and goggles. In evaluating goggle designs, CFD simulated an

Timothy Wei applied aerospace techniques to competitive swimming.
Image: RPI

HUSH-HUSH

As USA Swimming prepared for the Beijing Olympics, it was looking for an edge. It found one on the campus of Rensselaer Polytechnic Institute, where Timothy Wei, an expert in fluid dynamics, headed the Department of Mechanical, Aerospace, and Nuclear Engineering.

At the heart of the project, which was largely carried out in secret, Wei created a training tool that reports the performance of a swimmer in real time. He did it by modifying and combining force measurement tools from aerospace research with a video-based flow measurement technique known as digital particle image velocimetry.

"Swimming research has strived to understand water flow around a swimmer for decades, because how a swimmer's body moves the surrounding water is everything," said Russell Mark of USA Swimming, who was part of the project. "Dr. Wei's technology and methods presented us with a unique opportunity that swimmers and coaches could learn a lot from."

The technique involves computation and fluid dynamics, but it wasn't CFD—more like an experimental cousin. "DPIV is an experimental technique; CFD is a computer simulation," Mark said. "We seeded the fluid flow with tiny bubbles generated in a water flume. Using a high-speed camera, software tracked the movement of the particles/bubbles to visualize the flow; the video was overlaid with vectors that showed magnitude and direction of flow."

Sean Hutchison coached the U.S. Women's Olympic Swim Team that competed in Beijing. "This project moved the swimming world beyond the observational into scientific fact," he said. "The knowledge gained gave me the foundation for which every technical stroke change in preparation for the Beijing Olympics was based."

"Training and monitoring equipment is advancing at a tremendous rate, and coaches are increasingly enlisting the help of engineers and scientists to better understand how swimmers interact with the water," said Wei, who is now dean of engineering at the University of Nebraska-Lincoln. "There's no doubt that technology is driving faster lap times."