# Engineers take cues from nature

## New NASA institute seeks bio-inspired materials

**by Sara Peters**

Around the turn of the 20th century, Wilbur and Orville Wright were trying to design a flying machine, and unlike all previous designs, they were searching for one that would actually fly.

The brothers spent a lot of time studying pigeons, thinking that they could mimic certain characteristics. They noticed the flexibility of the wings and other characteristics that made it possible for even an ungainly pigeon to fly gracefully.

In December 1903 the Wright Brothers finally got their airplane to fly, but they never quite reached the ideal flight they'd imagined while watching birds soaring in the sky. The necessary materials just didn't exist at the time.

Now, as the 100th anniversary of the first flight draws nigh, researchers are inching closer to a flying machine that may more closely resemble the one in the Wright Brothers' dreams—and they, too, are watching nature for ideas.

NASA recently established a University Research, Engineering, and Technology Institute (URETI) to make advancements in the materials used in aeronautics and astronautics. Researchers in the institute, dubbed BIMat, are looking for "smart materials," materials that can sense the environment and respond to it.

They're also looking for materials that are lightweight, since weight is the major factor in determining the cost of flight.

For millennia, Mother Nature has been creating these types of materials. Since Mother Nature isn't available for the principal investigator position, she'll serve as muse for these scientists. They're studying her work closely, looking for cues on where they can create synthetic materials with the desired capabilities.

"We get the idea from biology, but not the materials," said Principal Investigator **Ilhan Aksay,** a professor in the Department of Chemical Engineering.

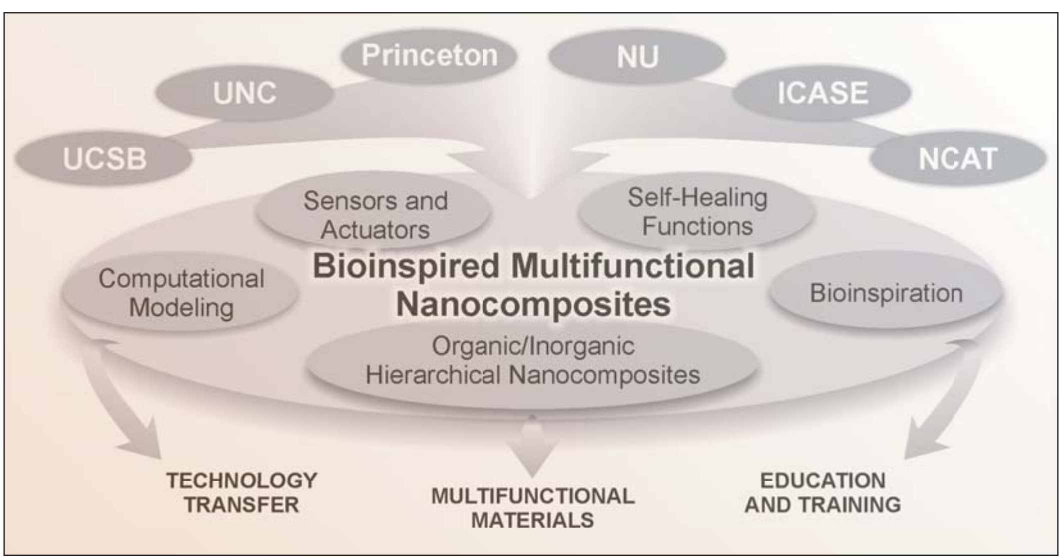
## Research team

Professor Aksay is a respected leader in materials research, specifically in the field of biomimetics, the study of synthesizing materials that mimic biological systems.

"All biologically built materials are complete systems," he said. "I've learned to think of even our bodies as systems."

Professor Aksay is flanked by associate directors, Professor Rod Ruoff of Northwestern University, Professor **Edward Samulski** *70 of the University of North Carolina at Chapel Hill (UNC), Professor Daniel Morse of the University of California at Santa Barbara (UCSB), and Manuel Salas of ICASE, a nonprofit research institute operated by the Universities Space Research Association at the NASA Langley Research Center.

The genesis of this institute goes back about a year, when Mr. Salas heard whisperings that NASA was going to establish several new URETIs, one



of which would focus on materials. Professor Aksay credits the current all-star team to the efforts of Mr. Salas.

"Manny had that vision," Professor Aksay said. "He was close to NASA and knew better what their goals were, and what they needed."

"Over the last four years ICASE has been trying to build a materials program," Mr. Salas said, "so when I saw that NASA Langley was going to get an institute in materials, I thought it was a good opportunity for ICASE to get involved."

Mr. Salas organized a team he believed was best suited for the task. He would need leaders in their fields with all the combined know-how essential to handling every aspect of this project. He would need experts in biology, chemistry, nanotechnology, synthesis, materials science, and mechanics.

The associate directors themselves come from varied backgrounds. Professor Morse works in the Department of Molecular, Cellular, and Developmental Biology at UCSB and specializes in genetic and biochemical engineering. Professor Ruoff is in the Department of Mechanical Engineering at Northwestern, where he specializes in nanomaterials science and engineering. Professor Samulski specializes in macromolecular chemistry in the chemistry department at UNC. Mr. Salas's specialty is fluid mechanics.

It's tempting to try and compartmentalize these researchers and designate discrete duties to each one based solely upon the names of their departments. Yet, that's a dangerous maneuver, because it's a truly interdisciplinary, collaborative effort, with a lot of overlapping of specialties and capabilities. Each associate director brings his own interdisciplinary team into the greater collaboration.

For example, the Princeton team includes Professors **Robert Prud'homme** and **Dudley Saville,** and Assistant Professor **Jeffrey Carbeck** of chemical engineering, Professor **Jean-Herve Prevost** of civil and environmental engineering, Chemistry Professor **Roberto Car,** and research scientists Drs. **Daniel Dabbs** and **Nan Yao.** Add them to similar teams at other institutions, and you have more than 30 researchers working on the same general problems.

## Combined efforts

Let's discuss these overriding problems. First, in aeronautics a major concern is weight. A plane can only be so heavy, or it won't stay in the air. A common term used in aeronautics is payload.

Everyone wants a larger payload. Payload is merely an expression of the amount of cargo a craft can transport over a given distance. Trade, passenger, and military aeronautics people would naturally like their aircraft to transport as much cargo as possible at once, but the weight adds up quickly.

Naturally, if the aircraft itself could weigh less while maintaining its carrying capacity and power, it could carry a heavier payload.

One way to make the plane lighter is to replace some materials with similar, lightweight materials.

Another way is to remove some of the heavier equipment, such as the hydraulic systems that adjust the wings. If materials with self-actuators could make adjustments themselves, hydraulics wouldn't be necessary, and payloads could increase.

In addition to reducing the weight of aircraft, NASA and the URETI team would like to create materials that simply perform better, can perform more tasks, and make flight safer or more precise. Specifically, they're looking for materials with sensory capabilities. They're also looking for "self-healing" materials, ones that can repair themselves.

"It's a rather ambitious project," Professor Samulski said. "It's sort of at that boundary of science and fiction."

*Photo by Frank Wojciechowski*

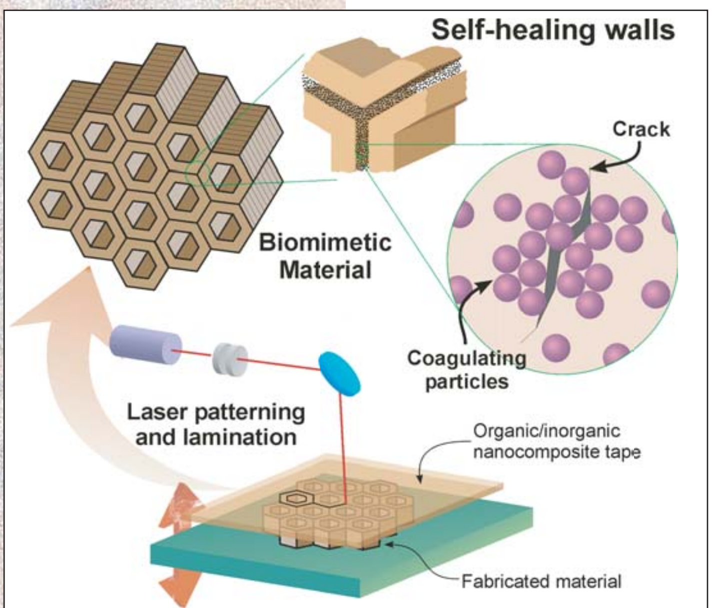
Members of the University Research, Engineering, and Technology Institute are, from left, Edward Samulski, Rod Ruoff, Daniel Morse, Ilhan Aksay, Manny Salas, and Kunigal Shivakumar.

The ultimate goal is materials, and the team will not turn away any brilliant discoveries for better materials, wherever they come from.

## Studying master

Since Mother Nature has long been creating lightweight, self-healing materials with their own built-in sensors and actuators, the team believes that a good way to begin their efforts is by studying Mother Nature's successes.

Currently, they're focusing




their study on bone and the nacre of abalone shells, since each exhibits properties useful in aeronautics and astronautics. Does this mean that the engineers are intending to build a 747 out of bone? Of course not.

"We extract the basic underlying principles," said Professor Morse. "What's special in biology that's not present in current manufacturing processes? Can we develop a creative solution to translate it into something that can be used on a practical level?"

Materials in nature are not suitable for the high-speed, high-temperature conditions that are required for jet-propelled flight.

There are concepts, however, that the scientists can borrow from natural materials and then adapt for their own needs. They want to synthesize organic/inorganic composites that mimic the capabilities of the natural materials.

Bone and abalone nacre are good ones to begin with because they're extraordinarily tough. They're strong or firm in texture, but they're flexible, and not as brittle as man-made ceramics. As stated in the BIMat URETI proposal, "The biopolymers in such biocomposites yield a combination of the strength of Kevlar, the toughness of silicones, and a breakage energy/unit weight greater than that of steel."

Bone and abalone nacre both exhibit self-healing properties, repairing wounds just as the skin of the human body does.

## Nanoscopic level

Researchers have detected that these substances manage this self-healing through the use of "sacrificial bonds," which disperse energy throughout a material and can reform.

The team will study these sacrificial bond structures much more closely to examine how they may be designed for aeronautic and astronautic conditions.

When the Wright brothers watched pigeons fly, they saw the fluidity of motion.

What they could not see, were the pieces of the puzzle that made such flexible movement possible.

They could not see the unified efforts of stiff ceramic and flexible collagen that make such range of motion possible at the nanoscopic level.

Yet, it is at this tiny level that the biological findings will be translated into practical mechanics, so the nanotechnicians have plenty of work ahead of them.

"Our role is to fabricate and test properties of what we hope will be revolutionary new composites, having remarkable mechanical properties," Professor Ruoff said.

The specialists in nanotechnology are working to synthesize inorganic/organic nanocomposites with miniaturized sensors and actuators embedded within the material. There are many challenges on this end as well.

"We want microsensors that could be distributed throughout the composite itself," Professor Samulski said. "How do we do that without adding a lot of weight? Maybe by using sensors that are derived from organic materials. If so, then we have to ask, 'How do we power those sensors?'"

All in all the group is optimistic and pleased to be a part of such a novel research project.

"We're tremendously excited to be part of this center," Professor Ruoff said, "and to be in this way connected with NASA Langley. We believe that there should be good opportunities for real innovations in materials."

"The magic and the excitement is really in the collaboration," Professor Morse said. "We'll succeed by building bridges between the teams."

"It's a new way of doing science for me," Professor Samulski said. "I can merely synthesize nanoparticles all day long and never worry about how they may be utilized. The feedback from the people at NASA who have real needs will color the way I do my research. Normally, I wouldn't be asking myself these questions or challenging myself in this way. That's one of the more positive dimensions of this project."