AIR FORCE OFFICE of SCIENTIFIC RESEARCH [AFOSR]

Manager of the Basic Research Investment for the Air Force

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Research HIGHLIGHTS

BIOMIMETICS:

New, Faster, Better Ways to Solve Air Force Needs

ABOVE: Scientists are now looking to nature to determine if certain biological processes can be mimicked for man-made use, hence the term “biomimetics.” As an example, AFOSR-funded researchers are studying how animals, such as snakes and vipers, are capable of detecting infrared at room temperature. Once understood, the application of this process could be of great value to the Air Force.

The Chemistry and Life Sciences Directorate of the Air Force Office of Scientific Research (AFOSR/NL), in cooperation with the Air Force Research Laboratories’ Materials and Manufacturing Directorate (AFRL/ML), has led the Department of Defense laboratory community in an area of biotechnology known as biomimetics. Meaning, literally, to imitate life, this field of study is an interdisciplinary effort aimed at understanding the operation of biological processes and the principles behind them and applying those principles to improve existing technology or to create entirely new technologies. Our ultimate vision for biomimetics research would produce innovative, new hybrid materials and devices with superior properties, as compared to synthetic or biological alternatives—like infrared sensors.

SENSORS: NATURE VS. MANMADE

Air Force scientists currently have several on-going efforts in the biomimetics area. One area of interest that has long intrigued researchers, is the natural ability of certain biological organisms to discern radiation outside of the visible light spectrum. Such discrete sensing proves critical to the Air Force due to the significant reliance upon, and threat of, detectors and sensors operating in the infrared-region of the electromagnetic spectrum. First, researchers must determine how biological organisms perceive infrared energy and then determine how to relate this to current man-made sensors. The ability to connect biological and synthetic technology is critical in exploiting and successfully transitioning biomimetic research. Biological systems accomplish this extreme infrared and thermal detection sensitivity without cryogenics (keeping the sensing apparatus extremely cold). Currently, man relies on toxic formulations of inorganic alloys to accomplish cryogenic infrared detection, yet nature does so by employing the basic elements of carbon, hydrogen, oxygen and nitrogen. The simplistic ingenuity of nature’s design may ultimately allow man-made thermal, room temperature, detectors to successfully compete with the photonic (cryogenic) detectors that currently dominate the infrared sensor field.

NATURE ON LAND (SNAKES AND BEETLES)

A multi-disciplinary university research initiative (MURI) led by Dr. A. J. Welch at the University of Texas at Austin, entitled “Biological Detection Systems for Electromagnetic Spectral Signatures,” examines certain beetles, pythons, and pit vipers for clues to the exploitation of their room temperature infrared detection capabilities. In addition to the MURI initiative, international researchers funded

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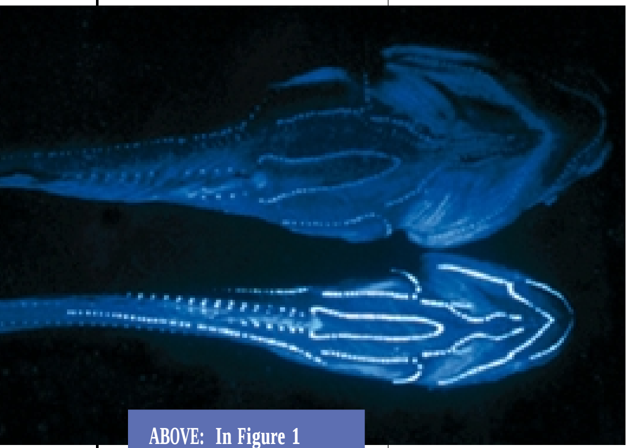
by AFOSR lend invaluable expertise to this field. In Japan, Drs. Shin-ichi Terashima and Richard Goris continue their thirty-year research program on snake-based infrared organs. In Germany, Helmut Schmitz directed his research on infrared-sensitive beetles to create a prototype infrared detector. Work is currently underway to transition this prototype technology to AFRL by refining the materials and miniaturizing the design.

NATURE UNDER THE SEA (FISH AND JELLYFISH)

The marine environment provides another source of biomimetic inspiration, especially in the area of optics and chromophores (light-sensitive pigments). In a terrestrial environment, the abundance of light allows organisms to send visible and ultraviolet signals by absorbing and/or reflecting certain wavelengths of light using chromophores and/or microstructures. For example, these signals are used to indicate toxicity, for concealment from predators, to deceive predators, and for mating, to name just a few. In an aquatic environment, sunlight only penetrates a few meters down from the surface. As a consequence, marine organisms have developed fascinating and intricate ways to generate their own light [see **Figure 1**].

FIGURE 1



ABOVE: In Figure 1 above, a number of marine animals generate their own light as a means to indicate toxicity, for concealment from or to deceive predators. As part of biomimetics research, scientists are studying these marine animals to better understand optics and chromophores (light-sensitive pigments) in hope of creating energy absorbing properties for use by the Air Force.

To exploit this unique aspect of nature's array of sensors, AFOSR funds researchers at the Scripps Institute of Oceanography, University of California at San Diego, in an effort to tap into this rich collection of biological chromophores. Dr. Fred Tsuji, an internationally recognized expert in the field of marine photochemistry, collaborates with researchers in AFRL/ML to explore the energy absorbing properties of these unique chromophores. From Tsuji's pioneering work on green fluorescent protein (GFP) from the jellyfish, to the bioluminescence exhibited by marine crustaceans, new molecules with uncharted properties are giving Air Force scientists new tools to attack materials science problems.

FROM "TRIGGERS" TO OPTICAL DETECTION SYSTEMS

Biomimetics research has focused on the isolation of biological triggers—those molecules that are responsible for the initial electromagnetic stimulus detection reaction in an organism. Currently, research emphasizes the coupling of biological triggers to practical synthetic optical detection systems, and in so doing, bypasses the impossible task of recreating a biological signal transduction system. AFOSR funds several biomimetic sensor groups in an effort to do just that. Researchers have been examining the use of liposomes and membrane channels as a biosensor platform. In cell biology, liposomes are synthetic membrane vesicles used for the study of membrane-defined events such as the transport or delivery of substances to a cell. For our purposes here, liposomes can be thought of as "bags" that carry signaling biochemical molecules; however, one can engineer liposomes to carry optical tracers like fluorescent dyes. By engineering biological triggers into the liposomes, the "bags" can be made to empty their contents in response to a specifically engineered stimulus—a significant step on the path to the design and fabrication of a practical optical sensory device.

THE MARRIAGE OF BIOLOGICAL SENSING AND OPTICAL OUTPUT

Central to the concept of converting electromagnetic biological sensing into a readily usable optical output—or creating a biosensor—is the process of molecular alignment. Often, optical properties can be created or enhanced by virtue of the specific placement or orientation of molecules. In an effort to address this technology hurdle, AFOSR oversees a MURI between research groups at Northwestern University under Chad Mirkin, and David Kaplan's team at Tufts University. This research consortium explores the use of Dip-Pen Nanolithography (DPN) for the placement and alignment of biological macromolecules. DPN technology, utilizing a computerized atomic force microscope, allows placement of individual molecules for the creation of extremely small and effective sensing devices. Although still in its infancy, this type of molecular alignment offers great promise to both the commercial and defense sectors with regard to revolutionary future sensing capabilities.

The diversity and resourcefulness of nature in accomplishing a task like electromagnetic radiation detection is clearly evident. However, less clear is how one can engineer these traits into a practical defense technology platform. In the realm of sensors, AFOSR and AFRL seek to make the seemingly impossible, practical.

Morley Stone, Ph.D.
Materials and Manufacturing Directorate
Air Force Research Laboratory

Improved Jet Engine Design from Soot Research

An AFOSR-funded researcher, Dr. Meredith Colket III of United Technologies Research Center (UTRC), East Hartford, CT, has produced a comprehensive model for the prediction of soot emissions from gas turbine combustors. This model has been incorporated into computational engine design methods used by Pratt and Whitney. The effectiveness of this new methodology was recently demonstrated in testing a new combustor design for the Pratt and Whitney 6000 aircraft engine. Based on the test results, the engine is projected to comply fully with existing International Civil Aviation Organization emission standards.

Computational tools have become an essential element of gas turbine design as the only cost-effective means to achieve preeminent design objectives. However, because of limitations in both current computational capability and basic physical understanding, computational design methods have been limited to qualitative screening of alternative combustor configurations. Future DoD performance requirements will necessitate new designs that will go well beyond evolutionary strategies relative to current engine designs. Therefore, AFOSR has addressed both computational software and physico-chemical deficiencies in order to produce quantitatively accurate computational design methodology.

Arguably, emissions represent the most stringent test of engine design capability. Emissions such as soot and oxides of nitrogen (NOx) are produced in trace amounts in combustors relative to the mass flow rates of fuel and air. However, these small amounts can cause serious damage to engine components and are stringently regulated because of their adverse environmental impact. Engine manufacturers, such as Pratt and Whitney, face these challenges for both military and commercial engine designs. For example, Pratt and Whitney's 2037 engine, used for commercial transportation systems, like the Boeing 757 aircraft, is also the basis for the F-117 engine that propels the Air Force C-17 cargo aircraft.

Under AFOSR's Aerospace and Materials Sciences directorate support, Colket, together with Mr. Robert J. Hall, at UTRC, and Professor Mitchell D. Smooke of Yale University, formulated a dual phase model for soot production. This model incorporates: (1) gas-phase chemistry to describe the progressive growth of gaseous hydrocarbon molecules to form incipient soot particles; and (2) aerosol dynamics to predict the agglomeration of these initial soot particles into larger particles that can be found in engine combustor environments. Dr. Saadat Syed, a Pratt & Whitney Fellow in Combustion, recognized the accuracy and computational efficiency of this model, a streamlined version of which has been incorporated into the design methodology for the Pratt and Whitney 6000 engine.

Figure 2 shows the model's prediction of soot behavior in combustors and **Figure 3** profiles the model's accuracy in predicting combustor temperature behavior.

Dr. Meredith Colket III performed this innovative research under the support of AFOSR Contract F49620-98-C-0008, managed by Dr. Julian Tishkoff, AFOSR Directorate of Aerospace and Materials Sciences, **(703) 696-8478.**

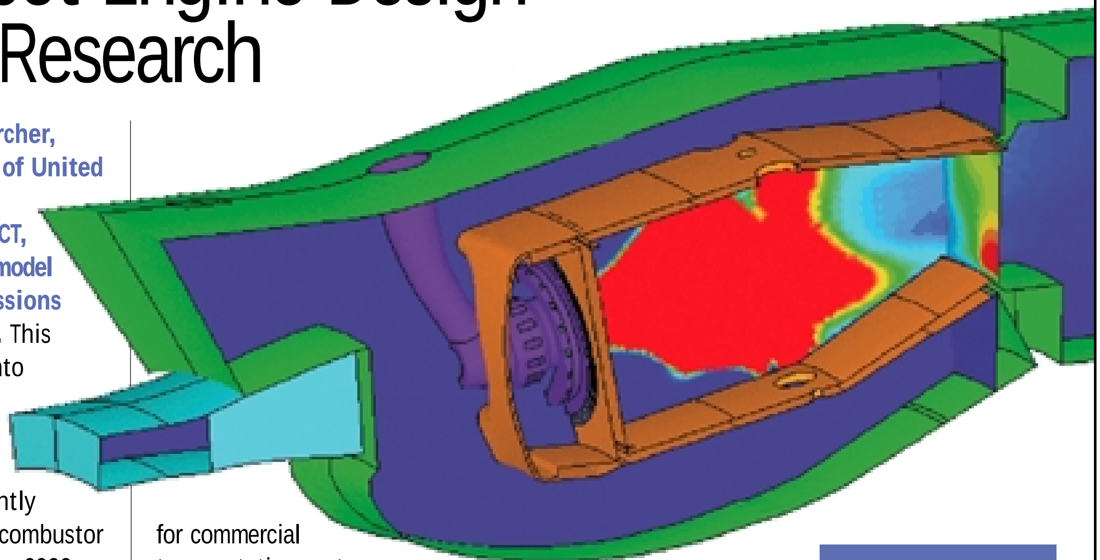


FIGURE 2

ABOVE: The Figure 2 illustration represents the ability of the model to predict soot behavior in combustors.

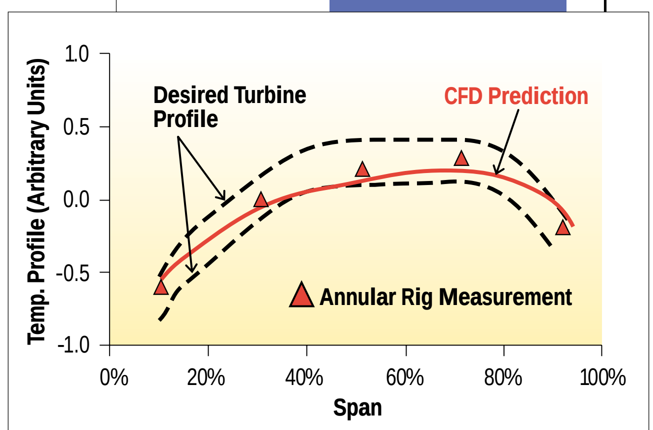


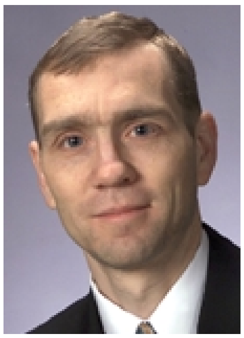
FIGURE 3

ABOVE: Baseline average exit temperature profile for CFD predictions and rig measurements relative to desired turbine profile.

Reservists Critical Workforce Component

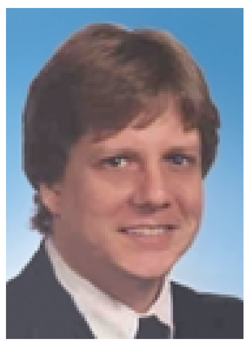
The Air Force Office of Scientific Research (AFOSR) has 25 Individual Mobilization Augmentees (IMAs) attached to the organization from the Air Force Reserve. They fit seamlessly into the research management work environment of AFOSR, and they contribute greatly to the mission. Highlights of three of AFOSR's IMA participants follow:

Captain Tom Johnson, AFOSR/NE, has a Ph.D. in Health Physics from Purdue University, an M.S. in Environmental Engineering from Northwestern University, and an M.B.A. from the University of Illinois. Working under the guidance of Dr. Robert Barker, Johnson organized over 75 papers from six countries to produce a compilation of abstracts called "ElectroMed 2001" from the second Conference on Biological Effects of Non-ionizing Radiation. Also, Tom has the distinct honor of being the first reservist to submit and have accepted, a research topic, Topic #16 "Biomolecular, Subcellular RF Sensing," for the DoD FY02 basic research announcement. The goal of this new research topic seeks to identify and understand biomolecular and sub-cellular effects in response to non-thermal and non-ionizing radio frequency exposures.



Major Kacie Haberly, AFOSR/JA, received her J.D. (juris doctorate) degree from the University of Puget Sound School of Law, Tacoma, WA. Haberly has focused on developing an AFOSR Operating Instruction for handling the patent processing within AFOSR—critical to grant/contract administration. Recently, she spent two weeks supporting our Tokyo operation (AOARD) and their contract service from 5th Air Force, Yokota AB, Japan. Since 5th Air Force provides legal support for the Tokyo office's contracts, she felt it critically important to develop a solid interface with the Yokota office, to ensure both offices have a better understanding of AOARD programs and needs. Haberly supports Major Tim Hicks in the AFOSR Staff Judge Advocate (SJA) office.

Captain Dwight Holland, AFOSR/IO, has a Ph.D. in Engineering from Virginia Tech, specializing in Systems/Human Effectiveness Integration and Masters Degrees in Systems Engineering and Geophysics. He has also served as a NASA/Stanford Faculty Fellow and is a member of the DoD Human Factors Technical Advisory Group. Since joining AFOSR, Holland has chaired three sessions at international conferences in systems/human effectiveness. In one session, he brought together scientists and medical personnel from the Navy, Air Force, Army, NASA and academia to discuss future directions and issues for military applications of laser visual corrective procedures. As a rated officer with more than 2,000 flying hours, he provides a unique perspective to issues facing the Air Force. Dr. Mark Maurice provides leadership for Holland's involvement here. Currently, Holland participates in managing a project with microbes growing in jet fuel in South America and is researching the potential effects on the health of fuel handlers and fuel integrity.



Research Highlights

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Research Highlights is published every two months by the Air Force Office of Scientific Research. This newsletter provides brief descriptions of AFOSR basic research activities including topics such as research accomplishments, examples of technology transitions and technology transfer, notable peer recognition awards and honors, and other research program achievements. The purpose is to provide Air Force, DoD, government, industry and university communities with brief accounts to illustrate AFOSR support of the Air Force mission. *Research Highlights* is available on-line at:

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