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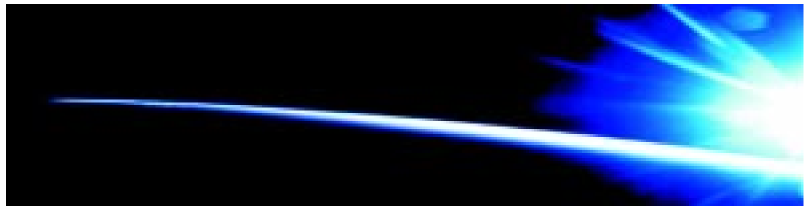

Research HIGHLIGHTS

NOV DEC 98

Control Theory Used To Reduce Costs For Air Force Weapon Systems

Air Force use of new flight control system design tools are significantly cutting design and development costs for current operational and test munition weapon systems. AFOSR-sponsored researchers at the University of Illinois Urbana-Champaign (UIUC), working with engineers at The Boeing Phantom Works in St. Louis, have developed and transitioned the new design tools for the Joint Direct Attack Munition (JDAM) and Miniaturized Munitions Technology Demonstration (MMTD) smart weapons.

The JDAM (operational) and MMTD (in test) gravity bombs use Global Positioning System navigation to accurately guide the weapon to target. Affordability is the primary objective in these programs. The new flight control design technology played a key role in meeting this directive by enabling Boeing to design low-order, simple flight controllers which:

- minimized the number of sensors,
- reduced parts count, and
- reduced weight, while meeting restrictive packaging and volume constraints.

The new MMTD smart bomb has the same military effectiveness (in tests) against fixed hard and soft targets as

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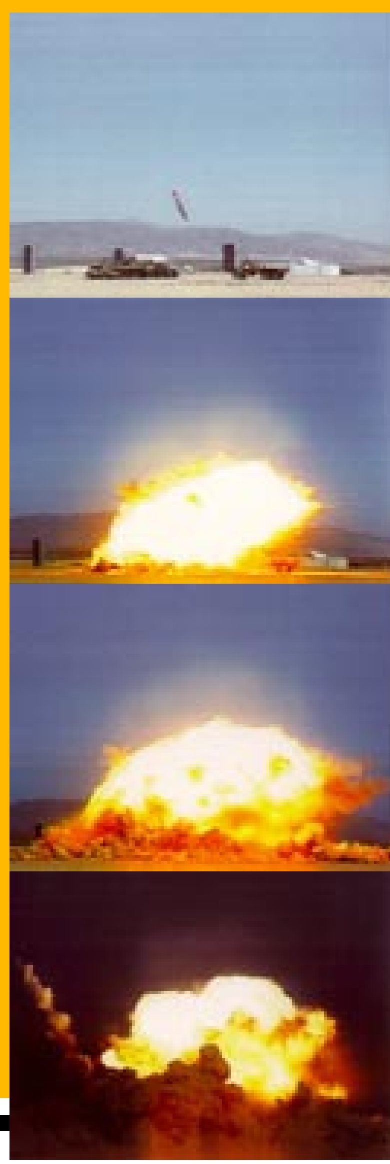
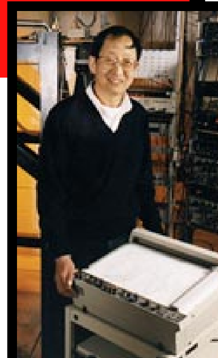
BELOW: Photo sequence showing JDAM test against ground mobile targets



Another AFOSR-Sponsored Researcher Wins Nobel Recognition



Prof. Daniel Tsui
Princeton University

At AFOSR, we're understandably proud of our track record of selecting world-class researchers to undertake the Air Force's technology challenges. This includes more than 30 Nobel Laureates in the fields of physics and chemistry supported by AFOSR prior to their recognition as a Nobel Laureate. In October, this trend continued with the announcement of Professor Daniel Tsui of Princeton University who shared in the 1998 Nobel Prize in Physics.

Dr. Tsui's award-winning "Fractional Quantum Hall effect" research was performed during his long career at Bell Labs. Subsequently at Princeton with AFOSR sponsorship, Dr. Tsui carried forward extensions of this work that will lead to miniaturized, high performance millimeter wave components used extensively in surveillance and communication systems. These smaller, faster components will play a key role in helping the Air Force to achieve its goals of 75 to 80 percent weight/volume reductions in electronic circuits early in the next century.

AFOSR congratulates Dr. Tsui and is proud to be associated with such highly recognized world-class scientific research.

Dr. Gerald Witt
Directorate of Physics and Electronics
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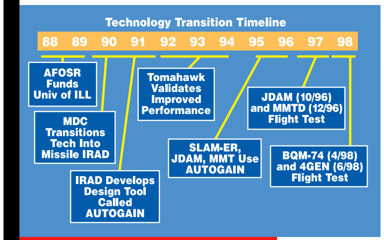
the currently fielded JDAM. However, the bomb's weight and volume decreased approximately 10-fold. These features will:

- significantly reduce logistics operations,
- enable new, low-observable aircraft such as the F-22 to carry many more bombs in their internal bays, and
- still maintain their stealth characteristics.

Dr. Kevin Wise



This is a stunning example of the impact of basic research. The size of the munitions was dramatically reduced because of the new controller design capability. Precise automatic control of the smart bomb's angle-of-attack gives it the same penetration capabilities against hardened targets as current munitions that are 10 times larger.

In 1988 and 89, under AFOSR support, Dr. Juri Medanic and Dr. William Perkins, professors at UIUC, developed several new control design methodologies that simultaneously satisfied a diverse set of control requirements including transient performance, disturbance rejection, robustness and reliability. One method they developed, now known as *projective control theory*, is based on finding suitable projections from high-order complex optimal designs to much simpler, low-order controller designs, which achieve near optimal performance while meeting the design constraints.

ABOVE: BQM-74 — Navy target Drone

ABOVE: 4th Generation Escape System

Dr. Kevin Wise, at the Boeing Phantom Works in St. Louis, leveraged the AFOSR-sponsored research. He developed a revolutionary flight control design tool called AUTOGAIN that completely automates autopilot design over the entire flight envelope. The enabling technology in AUTOGAIN was the projective control theory, used to project optimal state feedback designs into output feedback designs, thus eliminating hardware sensors in the implementation. AUTOGAIN's success has made it a "best practice" in the

continued on back page...

New Design Tools to Expand Use of Composite Materials

New composite materials design and life-prediction tools — derived from AFOSR-sponsored interdisciplinary research — will give structural material designers unprecedented creativity in tailoring composites for demanding, high-performance applications in next-generation aircraft.

Composite material payoffs include:

- Higher temperature performance and stability
- Accurate damage evolution and tolerance prediction
- Optimized fiber-matrix design patterns

Air Force goals of 40 to 50% weight/fuel/cost reductions for 21st century systems like the Air Superiority Fighter (F-22) and the Reusable Space Launch Vehicle (X-33) can be achieved by the expanded use of composites. Lightweight, high-strength composites offer several performance advantages over alloys currently in wide use. Composites inherent thermal resistance (more than double that of alloys) simultaneously affords higher operating temperatures, greater engine thrust, and lighter system weight resulting in thrust/weight ratio improvements of at least 15%. For example, composite propellant tanks on space vehicles can reduce overall primary structural weight by 30%.

However, composite use to date has been limited to non-critical subsystem applications due to the lack of comprehensive, interdisciplinary study of their damage modes under realistic

New Molecular Dynamics Theory Bene

A Georgia Institute of Technology professor's work has potential for important advances in the ability to detect missiles during their boost phase.

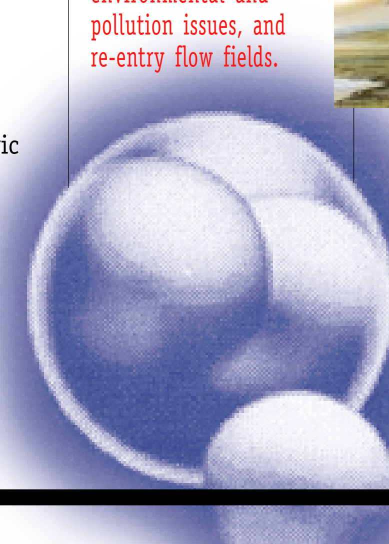
Dr. Raymond Flannery's microscopic theory of three-body recombination processes of electrons and ions in gases has improved researchers' understanding of collisions between atoms and molecules in specific highly excited states.

Understanding these recombination processes will further development of many Air Force capabilities:

- improved radar signatures
- enhanced missile signatures and atmospheric re-entry detection, identification
- advanced techniques to counter enemy detection of friendly missiles
- reduced missile/aircraft atmospheric pollution, and
- integrated circuit manufacture

By improving the understanding of rocket exhaust radar signatures, for example, the Air

Raymond Flannery's AFOSR-supported research is important for the understanding of many phenomena, including radar wave propagation, atmospheric recombination effects of missiles during boost phase, environmental and pollution issues, and re-entry flow fields.

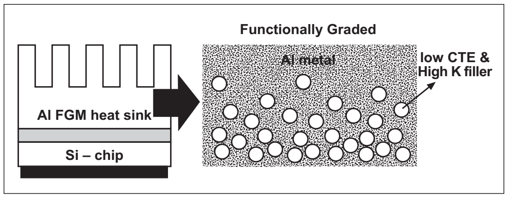


service conditions. Previous composite evaluations have been largely post-failure analyses and of marginal utility to the design community. Now with basic research advances from three university research programs, engineers will be able to uniquely optimize composites. The AFOSR-funded university researchers are integrating experimental and computational methodologies to characterize the complex nature of structural responses and damage modes of composite materials.

Next-generation military aircraft designers are making ever-increasing demands for higher performance materials. Composites offer significant advantages to affordably satisfy these emerging demands. The basic research accomplishments and insights from these research programs will enable the development of life-prediction tools for composites and provide the confidence required to expand the use of high performance, high efficiency composite materials in critical components such as wings, propellers, and engine fan blades.

HIGHER TEMPERATURE PERFORMANCE AND STABILITY

Dr. Minoru Taya of Washington University has developed a method to optimize a composite structure's thermal conductivity by adjusting its density and composition.



ABOVE: Higher Temperature Performing Composites. Structural material designers will be able to optimize a composite's thermal conductivity by adjusting its density and composition.

The ability of a specific composite material to dissipate heat while maintaining a desired degree of conductivity can be manipulated by varying the volume and type of material used as filler. Such flexibility allows a designer to match the composite's coefficient of thermal expansion to that of an electronic chip or diode and minimize thermal stress at the interface. This research is leading to increased composite use in military electronic circuitry and has attracted the attention of the electronic packaging industry including, Johnson Matthey Electronics (a major supplier of interconnect materials) and Intel Packaging Group.

ACCURATE DAMAGE EVOLUTION AND LIFETIME PREDICTION

Drs. Thomas Mackin and Nancy Sottos, of the University of Illinois are applying infrared imaging and micromechanics to provide detailed analysis of damage evolution and its relation to composite microstructure.

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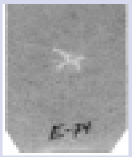
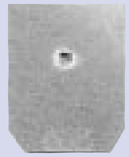
Photographic versus Infrared Images of Damaged Composites

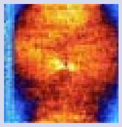
BELOW: Photographic images of glass fiber-reinforced epoxy composite test samples after 2 types of impact damage

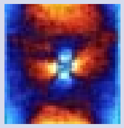


Partial Impact Penetration



Full Impact Penetration Punctures Material





Using an infrared imaging method (color photos above), researchers can precisely measure and quantify surface stresses (using a color scale) which escape optical detection in damaged composites. The lighter the color, the higher the stress as indicated in the vicinity of the impact areas. This new imaging tool can be used to trace the evolution of damage. Knowing how to quantify impact damage (ex: hail, dropped objects, birdstrikes, bullets) will allow the Air Force to predict the remaining lifetime of composite materials and to determine whether and when to replace them.

fits Research Tied to Air Force Tactical Operations

Force will be better able to detect missiles during boost phase. Molecular recombination within and around the rocket exhaust plume can yield specific signature information that could be exploited to enhance detection capabilities. This research will also improve the detection of objects — satellites, warheads, missiles — re-entering the atmosphere. During re-entry, objects are surrounded by plasma — the flow field created by atmospheric friction. As the understanding of flow fields and the accompanying molecular recombination improves, better detection systems will be developed. Neutralization of flow fields to avoid enemy detection or to maintain communications during manned re-entry may also become feasible.

Dr. Flannery's research has broader implications as well, including how pollutants influence atmospheric recombination. Because of his work and similar research, new methods of effectively dealing with environmental problems will be developed. As members of the world community, the U.S. military is interested in maintaining a strongly proactive environmental stance.

The AFRL Propulsion Directorate (AFRL/PR) is also interested in the applications of Dr. Flannery's work. His theoretical research will aid in under-standing interactions that take place in plasma deposition and etching, the processes often used in manufacture of large-scale integrated circuits. AFRL/PR is conducting research into the formation of dust in plasmas, a process that can interfere with deposition and etching.

AFOSR is the sole sponsor of Dr. Flannery's research on molecular recombination.

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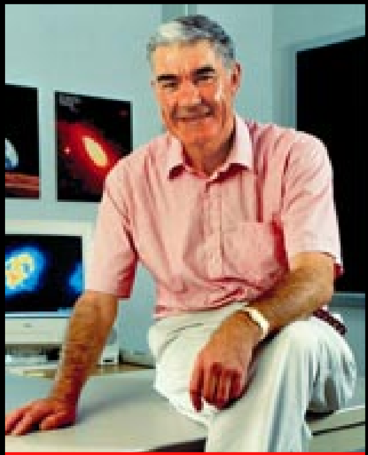
For more information about Dr. Flannery, visit our website at: www.afosr.af.mil or proceed to page 5



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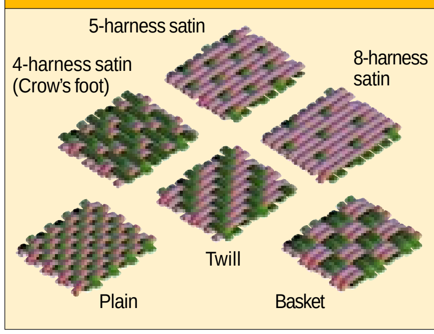
- Inducted as worldwide honorary member of Royal Irish Academy
- University of Belfast confers honorary Doctor of Science degree

New Design Tools to Expand Use of Composite Materials (con't.)

continued from page 3...

Dr. Mackin employs a thermoelastic infrared (IR) imaging method to measure full-field surface stresses in damaged composites caused by weather-related, accidental injury, or battle-damage type incidents. Dr. Sottos has investigated the micro-mechanics of interface damage such as that typically found in the layered material of an aircraft's wing skin. The infrared imaging method provides a precise quantitative measure of the current stress state, the evolution of damage during loading, and the resulting stress redistribution. Recent application of the IR method on polymer composites enabled a quantitative measure of impact damage and provided a new method for accurately predicting the remaining fatigue lifetimes of the damaged composites.

Weave Architectures



OPTIMIZED FIBER-MATRIX DESIGN PATTERNS

Dr. John Whitcomb of Texas A&M University has developed a three-dimensional simulation model for evaluating textile composites. Results indicate that the very complex process of damage initiation and growth can be predicted. The model traces damage evolution in textile composites subjected to thermal and mechanical loads and evaluates the relative influence of different fiber architectures such as woven, knitted, and braided patterns. The computational model evaluates several factors including fiber material properties, degree of waviness (texture), and the phase of undulation in adjacent fibers. Use of this new model will allow material designers to develop strategies for avoiding premature failures.

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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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Cover Story – continued from page 2...

Boeing Phantom Works. On many projects it has cut controller design effort by at least 50 percent. Besides the JDAM and MMTD, several other programs use the AUTOGAIN system including the Tomahawk cruise missile, the BQM-74 (Navy target drone), and the 4th Generation Escape System program.

Under AFOSR basic research support, Dr. Wise augmented these design tools in an important way. He developed new control system robustness analysis algorithms that have proved instrumental in analyzing a flight control system's dependency on knowing uncertain aerodynamic parameters. This analysis problem was of critical importance on the 4th Generation Escape System program where the mass properties and aerodynamic characteristics significantly vary between the 95 percent male pilot and 5 percent female pilot population. Wise's algorithms were used to accurately determine that the ejection's seat flight control system would perform over this wide range of parameters, culminating in the first ever supersonic ejection seat flight test at Holloman AFB, N.M.

For more technical information please contact Dr. Kevin Wise at: kevin.a.wise@boeing.com

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Do You Have An Idea For A Future Reseach Highlights Article?

Contact RH Editor Jane Knowlton at:

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Information in addition to hard copy version

AFOSR Principal Investigator Wins APS Will Allis Prize, Additional Recognition

Dr. Raymond Flannery, an AFOSR principal investigator at the Georgia Institute of Technology, has won the 1998 Will Allis Prize of the American Physical Society (APS) for his study of ionized gases. The APS recognized Dr. Flannery "for advancing the understanding of recombination processes, in particular for developing a microscopic theory of three-body ionic recombination; and for his novel applications of classical and quantum mechanical methods to the dynamics of atomic, molecular, and ionic systems."

Dr. Flannery's expertise is in the theory of atomic and molecular collision processes, particularly recombination processes at thermal and ultra-cold energies. The research cited by the APS - the microscopic theory of three-body recombination and novel appplications - was developed under sole AFOSR sponsorship.

Dr. Flannery is also working on theories of three-body atom-atom recombination for dimer formation in the Bose-Einstein condensate. His work is applicable to understanding anti-hydrogen production in positron-anitproton plasma at cryogenic temperatures and of three-body, electron-ion recombination at ultracold (milli-Kelvin) temperatures. He has also widely contributed to the theory of heavy-particle collisions, electron-excited atom collisions, Rydberg collisions, and ion-molecule reactions.

The APS prize came on the heels of Flannery's recent induction as one of 30 worldwide honorary members of the Royal Irish Academy. His alma mater, the Queen's University of Belfast, has also conferred on him the degree of Doctor of Science (honors causa) for "his distinction as a physicist."

Dr. Flannery noted, "The Royal Irish Academy, the American Physical Society, the Queen's University have all cited my work on recombination, supported exclusively by AFOSR."

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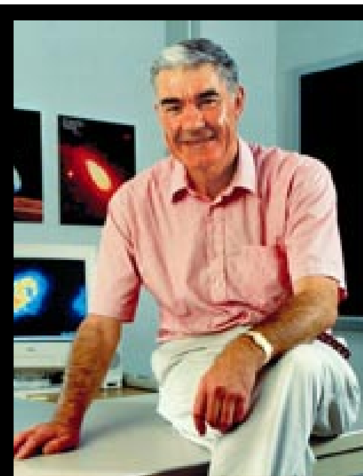

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