Air Force Office of Scientific Research

1951 - Present | Turning Scientific Discovery into Air Force Opportunity

AIR FORCE OFFICE OF SCIENTIFIC RESEARCH

We discover, shape and champion basic science that profoundly impacts the future Air Force

Basic research is the foundation of all scientific and engineering discovery and progress. It is what leads to new inventions and concepts—many of which are revolutionary. And the great thing about basic research is the mystery of it: while basic research investigators may start off trying to prove a particular theory, many times they end up going off in an entirely new direction, or their results are ultimately employed in a dramatically different way than they initially envisioned. This book describes a variety of those stories–a select chronicle of AFOSR's basic research initiatives over the past six decades.

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AFOSR Commanders/Directors

Col. Oliver G. Haygood
October 1951 – September 1953

Col. William O. Davis
September 1953 – August 1955

Brig. Gen. Don Flickinger
August 1955 – January 1956

Col. Adolf P. Gagge
January 1956 – March 1956

Brig. Gen. H. Franklin Gregory
March 1956 – October 1958

Brig. Gen. Benjamin G. Holzman
November 1958 – January 1960

Col. Adolph P. Gagge
January 1960 – October 1960

Dr. Knox T. Milsaps
October 1960 – January 1963

Col. Jack L. Deets
January 1963 – September 1963

Dr. William J. Price
September 1963 – August 1967

Col. Ivan C. Atkinson
August 1967 – July 1968

Dr. William J. Price
July 1968 – June 1974

Dr. William L. Lehmann
June 1974 – June 1978

Dr. Lawrence C. Kravitz
July 1978 – June 1981

Col. James E. Baker
June 1981 – June 1984

Col. Gerald P. D'Arcy
June 1984 – July 1986

Col. Alan J. Driscoll
July 1986 – March 1990

Dr. Helmut W. Hellwig
April 1990 – January 1996

Col. Robert L. Herklotz
January 1996 – September 1996

Dr. Joseph F. Janni
September 1996 – February 2001

Dr. Lyle H. Schwartz
March 2001 – July 2004

Dr. Brendan B. Godfrey
August 2004 – Jan 2010

Dr. Thomas P. Russell
February 2010 – March 2013

Dr. Patrick G. Carrick (Acting Director)
March 2013 - Present

Patrick G. Carrick, SES

Acting Director, Air Force Office of Scientific Research

Few organizations have the ability to effect revolutionary change. The Air Force Office of Scientific Research (AFOSR) has done just that—many times. For sixty years, AFOSR's revolutionary basic research accomplishments have been responsible for the introduction of critically transformative capabilities central to the creation of the world's most formidable Air Force.

AFOSR has forged the foundations of science in every mission critical area for today's Air Force, from integrated circuits, lasers, and stealth to anti-missile defense systems, hypersonics, and space travel. AFOSR personnel do not dream about what is possible--we accomplish what many believe is impossible. We focus on the science of the future today; enabling a future Air Force which will be far more technologically advanced that any peer.

AFOSR's mission is to find and fund the most dynamic and promising researchers—world class researchers are the essential cornerstone necessary to meet the technology challenges of future Air Force missions. AFOSR's long term success is not based on the desire to succeed in every research endeavor—far from it. AFOSR focuses on high-risk/high-payoff research investments that form the basis for revolutionary, long-term scientific and engineering discoveries. Our six decades of success are testament to the effectiveness of our approach: we discover and create the science to make current technologies obsolete—to make a revolutionary leap forward to the Air Force of the future. Air Force warfighters, along with our national economy, have been significant beneficiaries of a host of AFOSR research accomplishments.

The AFOSR legacy has proven that technological superiority is essential to the success of the United States Air Force and our nation, and much depends on our continued success. We are faced with nations that are fast demonstrating technologically sophisticated capabilities that may indeed result in unforeseen military threats. As such, we must continue to build on our solid foundation of high-risk/high-payoff basic research to ensure that the Air Force of the future can conquer any challenge that may threaten our nation.

Patrick G. Carrick, SES

Acting Director,

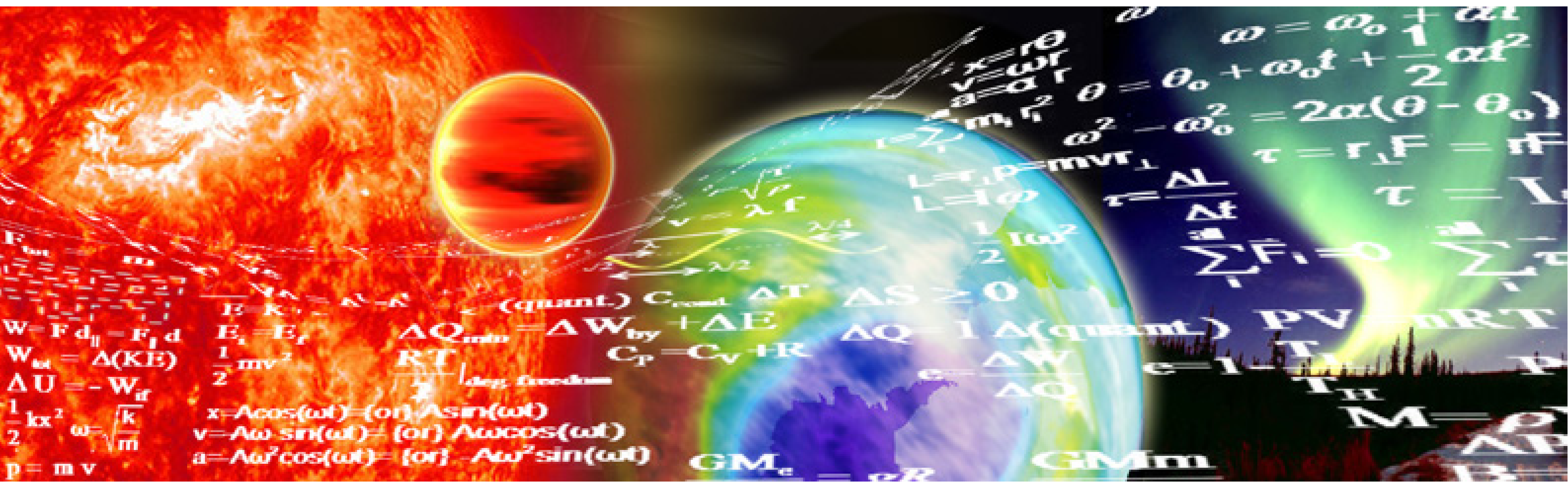
Air Force Office of Scientific Research

Introduction

The Air Force Office of Scientific Research (AFOSR), located in Arlington, Virginia, manages the United States Air Force's investment in basic research. AFOSR accomplishes this task through strong, productive alliances with a wide array of government agencies, the academic research community, and industry. AFOSR invests in long-term, broad-based research in aerospace-related science and engineering, and exploits revolutionary scientific breakthroughs to address the needs of the Air Force.

For sixty years, the accomplishments of AFOSR, ranging across a wide spectrum of aerospace sciences, have led to the creation of revolutionary new capabilities for the Air Force, and significant discoveries for the benefit of mankind. AFOSR's mission, to bring newly created scientific understanding and technology options from the scientific community, has generated tremendous payoffs for weapons and devices in use by the modern warfighter. Advances in laser technology, precision guidance, stealth capabilities, computer processing, materials and energy are but a few of the most significant areas of accomplishment derived from AFOSR-sponsored basic research.

As part of the Air Force Research Laboratory (AFRL), within the Air Force Materiel Command, AFOSR determines the specific investment in various basic research fields by reviewing the requirements identified by their customers – the warfighters – and continuously monitoring current scientific efforts to determine which may offer the most potential benefit to the Air Force mission. To understand the needs of the warfighter, AFOSR continuously reviews the overall Defense Science and Technology Strategy, the Defense Basic Research Plan, Air Force long-range plans, and actively participates in Air Force forecasting studies.

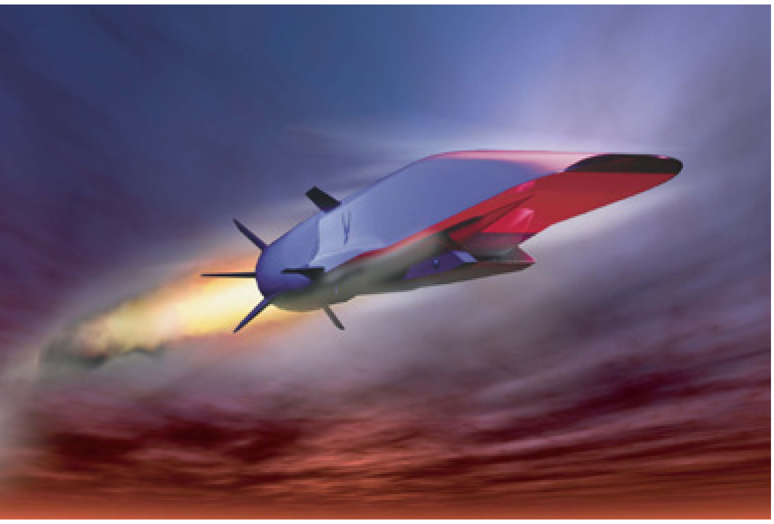


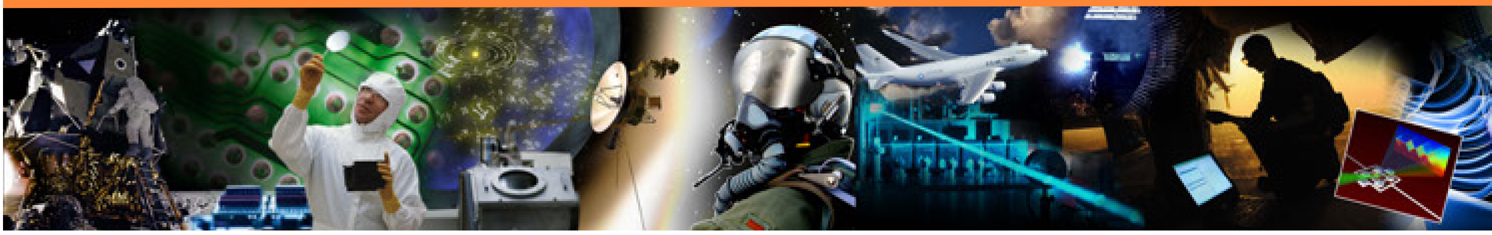
AFOSR does not conduct its own research and has no research facilities. Rather, AFOSR's highly trained scientists and engineers closely watch developments in their respective disciplines to identify far-term technologies for the Air Force of the future. These Program Managers respond to proposals and orchestrate the synergistic efforts of the talented and extremely productive teams of researchers in universities, industry, and AFRL laboratories.

The AFOSR investment in basic research programs is distributed between approximately 1600 grants and contracts provided to more than 380 academic institutions, over 70 contracts with commercial firms, and more than 300 internal Air Force research efforts performed within AFRL's eight technology directorate laboratories. Additionally, AFOSR manages a portion of the basic research investment of various agencies of the Department of Defense, such as the Defense Advanced Research Projects Agency, and other government agencies such as the National Aeronautics and Space Administration.

AFOSR has three foreign offices – the International Office Europe in London, United Kingdom, the International Office Asia in Tokyo, Japan, and the International Office South in Santiago, Chile. The International Office North collocated with AFOSR in Arlington, Va., serves as the international point of contact for AFOSR. Together these offices provide access to international research and related organizations for AFRL's entire technology community.

During the past sixty years, AFOSR has funded thousands of basic research programs. Many of these research endeavors have paid off handsomely, and while AFOSR focuses the scientific community on Air Force warfighter needs to enhance our nation's security, the commercial world benefits as well with the transition of innovative technologies. But none of the AFOSR success stories would have been possible without the expertise of the researchers with whom we work. The following highlights of AFOSR-funded research constitute but a small portion of the many programs that have successfully transitioned into the applied and advanced areas – all undertaken in the spirit of partnership, governed by excellence in research, and dedicated to the accomplishment of the Air Force mission.





AFOSR A Brief History

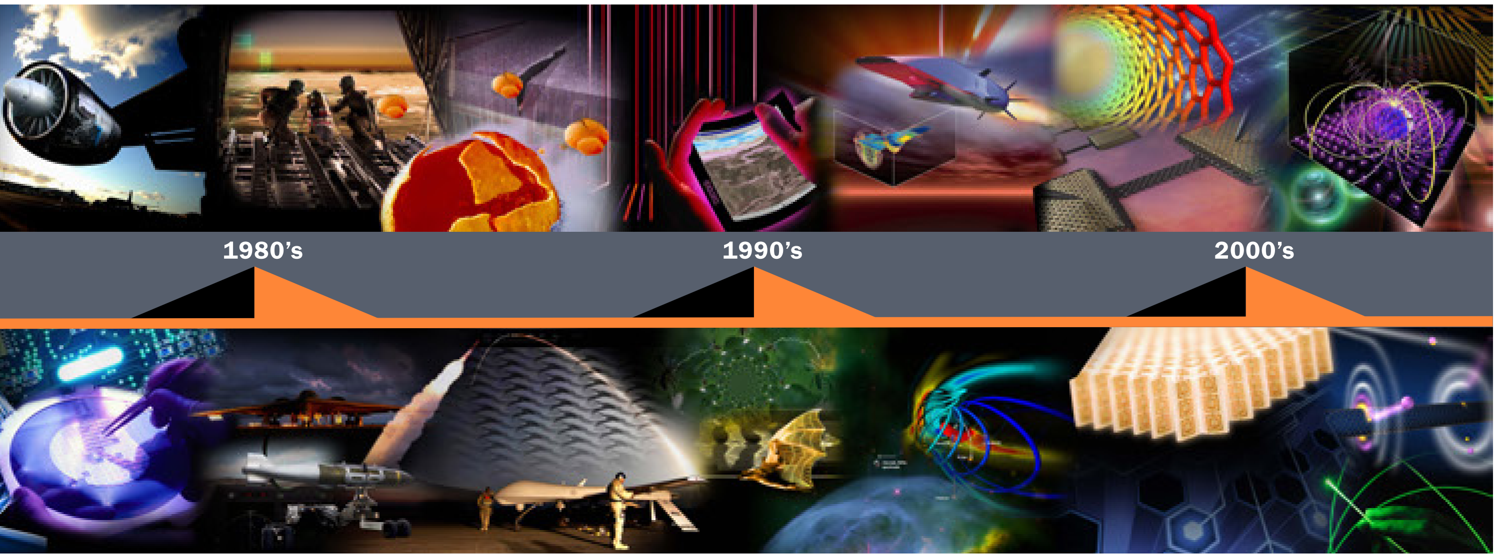
The wide-ranging and highly successful United States Air Force basic research program that exists today was born out of the need to address not only a longstanding shortfall in military basic research, but to also help address the overall historical neglect of aeronautical related research and development.

Such was the sad state of affairs during World War I that U.S. pilots, for the most part, flew second-hand European aircraft during the war.

Decades of neglect and deficiency became quite obvious during World War II when massive civilian-led research and development efforts were hastily established to develop much needed weaponry and support requirements.

This program of civilian-based research fit well with the future plans of General Henry "Hap" Arnold, the head of the Army Air Forces. In November 1944, Arnold brought together a distinguished cadre of scientists to form the Army Air Forces Scientific Advisory Group. Theodore von Karman, one of the world's leading aerodynamicists, chaired the group that continues to this day as the Air Force Scientific Advisory Board. Arnold convened this group because he was convinced that "the first essential of air power is preeminence in research," and the war clearly demonstrated the Army Air Force could ignore the frontiers of science only at the nation's peril.

Arnold did not want the nation to be caught unaware and unprepared again, and as such, he supported a strong research and development program. And Arnold was not alone; for many scientists, the weaponry employed during the war was impetus for not only a strong applied research effort, but for a dedicated basic research program as well.



There were other strong advocates for national security related scientific research, but they differed as to how to go about it. Dr. Vannevar Bush, the Director of the WW II era Office for Scientific Research and Development, felt such research should be conducted by civilian agencies. It was in his 1945 report *Science, The Endless Frontier,* wherein Bush noted that basic research was: “the pacemaker of technological progress.” Bush recommended the establishment of what would ultimately become the National Science Foundation (NSF).

While Bush and von Karman may have disagreed about the degree of service involvement in Research and Development, they were in complete harmony about the necessity of Research and Development for the nation’s future security.

With the establishment of an independent Air Force after the war, the importance of scientific research was given emphasis when the Office of Air Research was established in February 1948 as part of the Air Materiel Command at Wright Field, Ohio. Several key studies accomplished in 1949, especially the Ridenour Report, were instrumental in gaining additional high level support for an expanded Air Force Research and Development effort, as well as the establishment of the Air Research and Development Command in January 1950. In October 1951, the Air Force Office of Scientific Research (AFOSR) was created to manage basic research for the Air Force.

The establishment of AFOSR was of great consequence, because the Air Force had acted on the awareness that had been growing since the early days of WWII. Not only were science, technology and the Air Force intimately associated, but it was also recognized that the strength of the nation’s research community could add immeasurably to the service’s capabilities. Today, as an integral part of the Air Force Research Laboratory (AFRL), the mission of AFOSR has remained the same: to seek out and apply the powerful attributes of revolutionary basic science to meet the future requirements of our Air Force.

1951: AFOSR was initially located in the Sun Building in downtown Baltimore, M.D., as a staff element of the Air Research and Development Command.

AFOSR Mission Statement

AFOSR continues to expand the horizon of scientific knowledge through its leaderhsip and management of the Air Force's Basic Research program. As a vital component of AFRL, AFOSR's mission is to support Air Force goals of control and maximum utilization of air, space, and cyberspace.

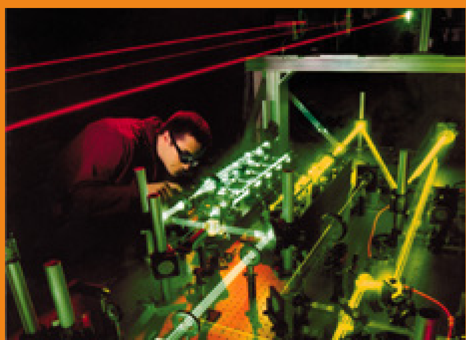
AFOSR accomplishes its mission by investing in basic research efforts for the Air Force in relevant scientific areas. Central to AFOSR's strategy is the transfer of the fruits of basic research to the academic community, directorates within AFRL and industry.

PARTNERS in Basic Research

AFOSR does not conduct its own research. Rather, with its staff of highly trained scientists and engineers, it manages the Air Force basic research program via three key partnerships.

The University Connection:

Academia provides much of the backbone for our nation's technological progress while performing the bulk of basic research. In addition to providing a prolific source of new knowledge and ideas, university research offers an exceptional training ground for developing and mentoring future scientists and our national defense and economic security.



Air Force Intramural Research:

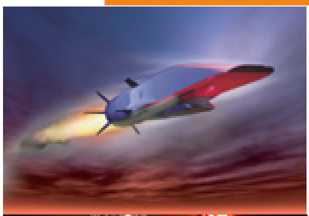
AFOSR works closely with the other AFRL Technical Directorates to nurture and support quality research and, where advantageous, integrate intramural and external research efforts to transition the latest basic research discoveries to follow-on levels in the research and development chain.

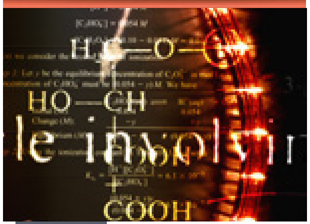
Small Business Technology Transfer (STTR) Program:

The primary objective of the STTR program is to involve small businesses in Air Force-relevant defense research and enable them to commercialize their innovative technologies for the advancement of U.S. economic competitiveness. Specifically, the STTR program is designed to provide incentive for small companies, academic institutions and non-profit research institutions (including federally-funded research and development centers) to transfer technical ideas from the laboratory to the marketplace.

AFOSR Technical Divisions and the International Office

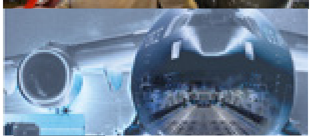
RTA Dynamical Systems and Control





The Dynamical Systems and Control Department lead the discovery and development of the fundamental and integrated science that advances future air and space flight. The broad goal of the division is to discover and exploit the critical fundamental science and knowledge that will shape the future of aerospace sciences. A key emphasis is the establishment of the foundations necessary to advance the integration or convergence of the scientific disciplines critical to maintaining technological superiority. A wide range of fundamental research addressing mathematics, materials, fluid dynamics, and structural mechanics are brought together in an effort to increase performance and achieve unprecedented operational capability. The division carries out its ambitious mission through leadership of an international, highly diverse and multidisciplinary research community to find, support, and fosters new scientific discoveries that will ensure future novel innovations for the future Air Force.

RTB Quantum and Non-Equilibrium Processes

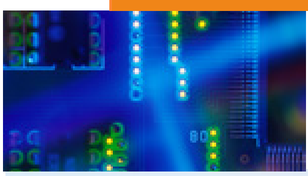


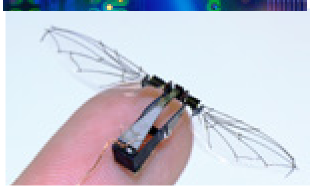
The Quantum and Non-Equilibrium Processes Department leads the discovery and transition of foundational physical science to enable air, space, and cyber power. Research in this area of physics generates the fundamental knowledge needed to advance U.S. Air Force operations, both from the perspective of sensing, characterizing, and managing the operational environment as well as developing advanced devices that exploit novel physical principles to bring new capabilities to the U.S. Air Force.

RTC Information, Decision and Complex Networks

The information, decision, and complex networks Department is designed to support many Air Force priority areas including space situational awareness, autonomy, and cyber. The programs in the Department include Complex Networks, Computational and Machine Intelligence, Dynamic Data Driven Application Systems, Foundations of Information Systems, Information Operations and Security, Mathematical and Computational Cognition, Science of Information Computation and Fusion, Sensing Surveillance and Navigation, Systems and Software, and Trust and Influence.

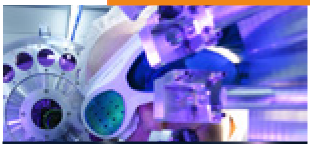
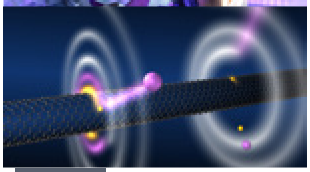
RTD Complex Materials and Devices





The Complex Materials & Devices Department leads the discovery and development of the fundamental and integrated science that provides novel options that increase operational flexibility and performance relevant to the Air Force. A key emphasis is the establishment of the foundations necessary to advance the integration or convergence of the scientific disciplines critical to maintaining technological superiority. The Department carries out its ambitious mission through the leadership of a global, multidisciplinary research community to identify research to support and foster new scientific discoveries that will ensure future innovations to transform the Air Force of the future.

RTE Energy, Power and Propulsion

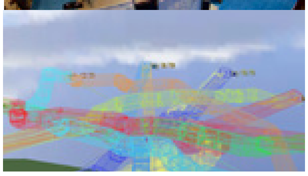
The Energy, Power & Propulsion Department leads the discovery and development of innovative fundamental science addressing a broad spectrum of energy-related issues. The overarching goal of the department is to discover and exploit the critical knowledge and capabilities that will shape the development of energetically-efficient future Air Force systems. In pursuit of this goal, the Department proactively directs an international, highly diverse and multidisciplinary research community to find, support and foster new scientific knowledge that will provide the foundation for unprecedented energy efficiency in future systems

The AFOSR International Office

To enhance AFOSR's research portfolio with the latest scientific and engineering advancements around the world, the International Office (AFOSR/IO) consists of four geographically strategic divisions. The European Office of Aerospace Research and Development (EOARD), in London, United Kingdom, provides coverage of Europe, the Former Soviet Union, the Middle East, and Africa; the Asian Office of Aerospace Research and Development (AOARD), in Tokyo, Japan, has an area of responsibility that includes Asia, India, and Pacific Rim countries, including Australia and New Zealand; the Southern Office of Aerospace Research and Development (SOARD), in Santiago, Chile, provides coverage throughout the Latin American region; and the International Office North (AFOSR/ION), as part of AFOSR in Arlington, VA, serves as the Washington DC liaison for AFOSR's international activities.

The mission of the International Office is to discover world-class fundamental research of interest to the US Air Force, and to bridge and build mutually beneficial relationships between scientists overseas, and scientists in the United States, that will result in the acceleration of S&T achievement. The three overseas divisions accomplish this mission by way of three main programs:





– The Window-On-Science (WOS) program is an invitational program for prominent international scientists to visit and meet with scientists in the Air Force Research Laboratory. Visitors provide a seminar on their research activity, and have the opportunity to engage in technical discussions with their Air Force counterparts.

– The Conference Support Program (CSP) is designed to provide financial support for overseas workshops and conferences that are in scientific areas of interest to the Air Force. These meetings are attended by AFRL personnel, and offer the opportunity for international discovery and interchange.

– The Research Grants and Contracts program directly funds research overseas. Proposals in response to the AFOSR Broad Agency Announcement (BAA) are accepted year-round and evaluated by AFOSR Program Officers and Air Force researchers. Grants may be single or multi-year, and grants may be for stand-alone research, or may supplement existing research efforts.

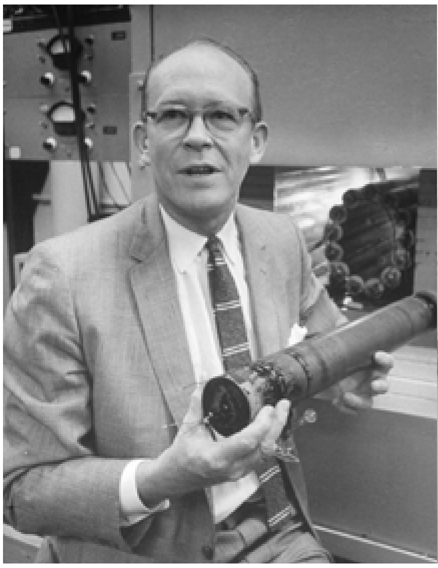
The International Office also administers the Engineer and Scientist Exchange Program (ESEP) for the Deputy Under Secretary of the Air Force for International Affairs. This program allows Air Force scientists and engineers to spend up to two years as researchers in defense laboratories overseas, and allows scientists and engineers from overseas defense laboratories to do research in Air Force facilities in the US. In addition, the International Office administers the Window-on-the-World (WOW) program, allowing AF scientists and engineers to do research in overseas universities and other non-government institutes for up to six months.

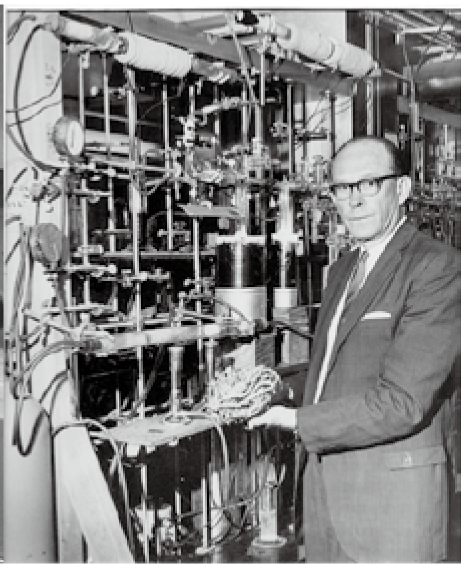
Finally, the International Office combines these tools with site visits and data mining to develop comprehensive strategies, programs, and initiatives to maximize the return on AFOSR's overseas investments.

1950's

AFOSR BASIC RESEARCH

SIX DECADES OF SUCCESS





"Seldom has such a single discovery in chemistry had such an impact on the thinking of so many fields of human endeavor. Seldom has a single discovery generated such wide public interest."

-Dr. Libby's 1960 Nobel Prize Citation

Radiochemical Developments (1951-1954)

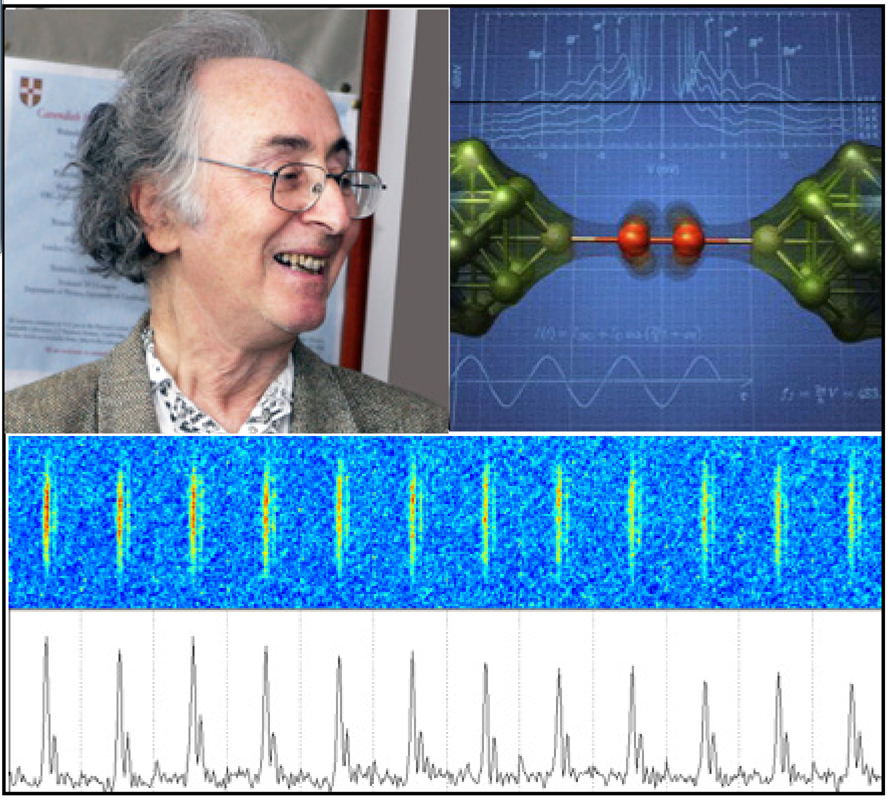
From 1947 through 1954, much of the research work in the field of radiochemistry, performed by 1960 Nobel prize winner Dr. W. F. Libby at the University of Chicago, was supported by the Air Force. Many significant scientific developments resulted directly from this work. The total contributions to the scientific and technological community consists of not only the methodology and techniques that were a direct consequence of his work, but also include many later investigations in allied fields which would not have been possible, or at the least, highly problematic, had it not been for the basic research supported by AFOSR. Libby studied radioactive isotope carbon-14 since its discovery in 1941 and is best known for his radiocarbon dating techniques. In 1947, Libby and his students at the Institute for Nuclear Studies developed the method of C14 dating using a highly sensitive Geiger counter. Libby's dating technique is extremely valuable to earth scientists, anthropologists and especially archaeologists, virtually eliminating the educated guesses about the ages of various artifacts based on evidence found at the site. This technology resulted in a new chronology that knits together archaeological findings from around the world. His Nobel Prize citation read: "Seldom has such a single discovery in chemistry had such an impact on the thinking of so many fields of human endeavor. Seldom has a single discovery generated such wide public interest." AFOSR funding for Libby covered a wide range of requirements: radioactive isotopes, optical transparency, high-pressure chemistry, electron tunneling, pollution control catalysts, and industrial chemistry in space.[1]

Early Stealth Research: HF Electromagnetic Scattering & Stealth Coatings (1950s)

In 1951 and 1952, AFOSR awarded research grants to Dr. Joseph Keller to explore ways in which airborne vehicles would be less susceptible to radar. Soon afterwards, he developed the equations that helped lead to radar reflectivity solutions for stealth applications. Keller's work and related refinements were used in the early 1960s by a Soviet scientist, Pyotr Ufimtsev, to describe a new method for calculating the Radar Cross Section (RCS) across a large surface. Ufimtsev's work was subsequently utilized by the United States Air Force to design a software program which would predict the RCS of a faceted aircraft design, leading to the development of the F-117 stealth fighter. Ufimtsev acknowledged Keller's key contribution to his seminal work in 1995. AFOSR also funded two contracts in1952 and 1954 to "explore the possibility of reducing aircraft RCS" with radar absorbent materials. The results of these initiatives ultimately fed into proprietary stealth applications.[2]

Superconductivity (1951-present)

Superconductivity, or the total lack of DC electrical resistance in certain materials when cooled to a temperature near absolute zero, has been a key field of endeavor for AFOSR research for over fifty years. In 1964, an AFOSR-funded team at the University of California, San Diego (UCSD) led by Professor Bernd Matthias, discovered a new category of superconducting materials, and it was in the early 1960s that Dr. Brian Josephson, who discovered what became known as the AC and DC Josephson effects in superconductors, was mentored as a graduate student under an AFOSR grant to Dr. Phil Anderson (who shared the 1977 Nobel Prize in Physics). The AC Josephson effect forms the basis of the standard volt, while the DC Josephson effect provided the basis for what became at that time, the world's most sensitive magnetometers and fastest, lowest power switching elements, leading to a new generation of electronic components. Josephson shared the Nobel Prize in physics in 1973. Dr. C.W. (Paul) Chu began his research in superconductivity with AFOSR support while a graduate student at UCSD and went on to do groundbreaking work in discovering and stabilizing high transition temperature superconductors, which in the form of small, sharp, low-loss electromagnetic filters, are used in Air Force telecommunication systems, resulting in more secure communications and superior radar systems. The fundamental research utilizing superconducting magnetometry sponsored by AFOSR in the 1980s and 1990s was instrumental in the detection of active corrosion and defect structures in aging aircraft. It is significant to note that a very large part of the fundamental knowledge regarding superconductivity is due to early AFOSR-sponsored research during the 1960s, and the program continues today to provide funding for study of this unique phenomenon.[3]



Gas Transpiration Cooled Electric Arc Anodes (1952-1956)

AFOSR-funded research led to the development of a highly effective electric arc apparatus for heating gases to a high temperature. Previously, heating with an electric arc was impractical since the heat formed would melt and vaporize the anode. In the new apparatus this heat is carried away by the transpiration of gas out of numerous tiny pores in the anode and fed into the arc flame where the highest heat is found. The electric arc is also very efficient for converting the electrical energy into the heat of the gas with an efficiency of 90%. At the time, this was of particular significance

for wind tunnel applications, which were limited by their ability to produce and handle very high-temperature gases needed for high-speed flight simulation. The transpiration-cooled arc was doubly suited for this application because the electrodes did not melt, thus eliminating any contaminating material to the wind tunnel gas flow. The transpiration-cooled arc was also an intense source of light and used for solar simulation in a space chamber.[4]

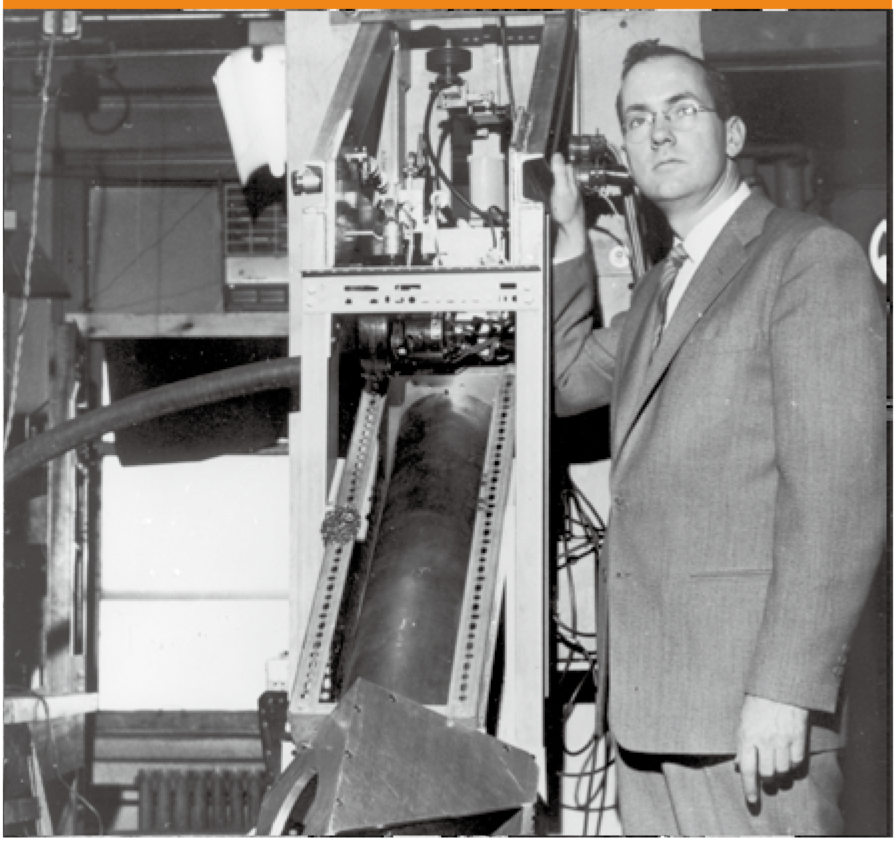
Matrix Isolation Cell (1952-1954)

In the early 1950s, AFOSR-sponsored research by Dr. George Pimentel at the University of California, Berkeley, for a better way to observe short-lived chemical species. Dr. Pimentel developed an ingenious matrix isolation method in low temperature chemistry. Highly reactive free radicals or unstable species were immobilized in an environment, or matrix, that assured non-reaction, rigidity, and transparency under infrared spectroscopy. Inert gases, such as argon, were found to be most satisfactory matrices and the technique was utilized to study unstable species for possible use as rocket propellants. The technique was subsequently applied in academic and industrial studies for fast reactions. AFOSR also supported Dr. Pimentel in his successful effort to develop the chemical laser, demonstrated by Pimentel and Jerome Kasper in 1965.[5]

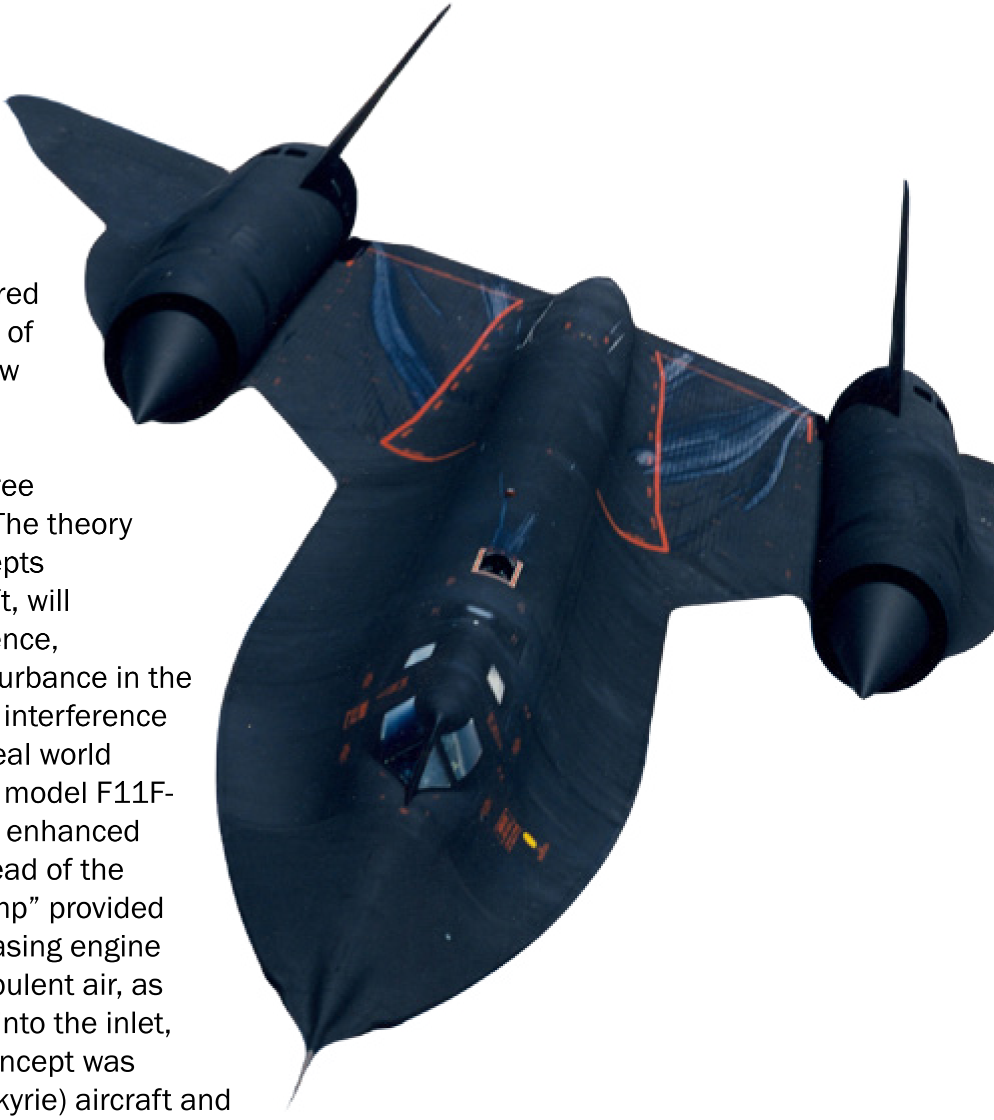
Maser (1953)

The history of the laser goes back to 1953, when as members of the Joint Services Electronics Program (JSEP), AFOSR partially supported the research of Dr. Charles Townes, J. P. Gordon and H. J. Zeiger at Columbia University, leading to the development of the MASER in 1954. The result was the first amplifier using energy changes in the electrons of a gas to amplify signals in the microwave region. The gas used in the working element was ammonia. Townes' aim was to build the MASER with well understood materials that would yield simple, predictable results. True to the aim of basic research, he was more interested in demonstrating a technique—and understanding the principles behind it—than in developing an immediately useful device, but Dr. Townes' effort led to an explosion of laser related breakthroughs by numerous researchers who were supported by AFOSR.[6]

Dr. Charles Townes, 1954



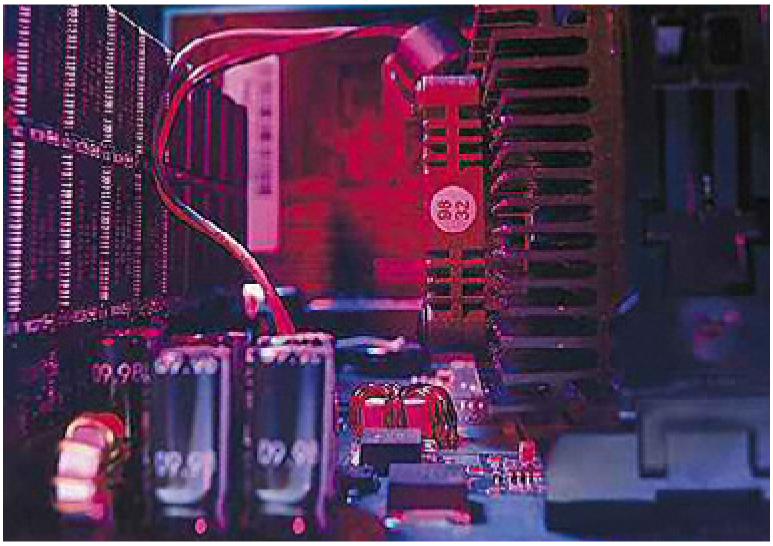
Favorable Interference: Three Dimensional Interference Effects for High Speed Aircraft (1953-1956)



From 1953 to 1956, AFOSR-sponsored research at the Polytechnic Institute of Brooklyn regarding high speed airflow as an aid in modern aircraft design. This research led to the formulation of a theory commonly known as "three dimensional interference effects." The theory involves use of certain design concepts which, for a given high speed aircraft, will produce a favorable airflow interference, which decreases the amount of disturbance in the airflow from the point of initiation of interference to the rear of the aircraft. The first real world application of this theory was to the model F11F-1F U.S. Navy aircraft, resulting in an enhanced contour surface on the fuselage ahead of the engine air inlet. This enhanced "bump" provided much better airflow as well as increasing engine efficiency by removing a layer of turbulent air, as well as compressing the air moving into the inlet, resulting in increased power. The concept was subsequently used on the B-70 (Valkyrie) aircraft and is employed to this day in the most advanced aircraft designs.[7]

Mach Meter Design (1953-1958)

With the advent of the Century series (F-100 to F-106) aircraft, Mach 1+ speeds adversely affected the accuracy of conventional airspeed indicators. AFOSR-funded research programs at several institutions (Princeton (co-funded with ONR), Cornell and the Aerospace Research Laboratory), solved the problem through research on the interaction between shock waves created by supersonic flight and the boundary layer of air that formed between the surface of the aircraft and the free air stream flowing past the aircraft. A blunt body shape placed in the flow field ahead of the fuselage results in a more accurate airspeed indication. The Aeronautical Research Laboratories designed Mach meter indicators using this principle were employed on the Century series, as well as the YF12A—later designated as the SR-71.[8]



Sampled-Data Control Systems (1953-1960)

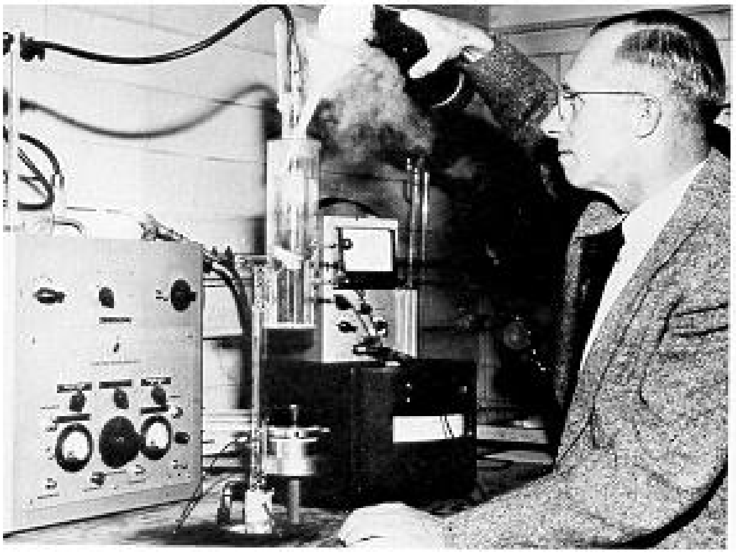
One of the most significant programs in the history of AFOSR is the basic research effort in support of sampled data control systems.

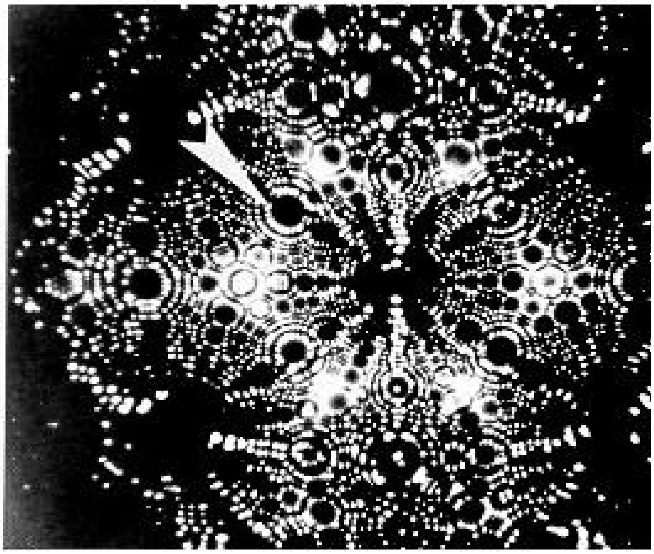
Since its inception in 1953, this effort has made major contributions in the field of control systems theory. The objective was to formulate theories for the marriage of new advances in the fledgling field of digital computers, as well as data links, to automatic control systems. In addition, there was a dedicated AFOSR effort to train research engineers to further develop and advance control systems theory. Control systems are essentially devices that regulate the output of a system in accordance with information originating from within or outside of the system, and as the information that is used to control the output of a system is in the form of electronic signals, a discrete portion can also be used to track the overall performance of a system. Early in the 1950s, it became apparent that computers would soon dominate the control system field, and AFOSR endeavored to develop basic underlying theory and rational design principles for the development of control systems which use digital processing of control information. In 1960, AFOSR funding resulted in three papers describing two significant mathematical developments in sampled data theory under Professor E.I. Jury at the University of California, Berkeley: the Modified z Transform Theory and the p Transform Method. This research was subsequently utilized for NORAD's massive Semi-Automatic Ground Environment (SAGE) system, a digitally automated control system for tracking and intercepting enemy bomber aircraft, which was operational from 1959 to1983, as well as being employed in guided missile control systems, and the trajectory and rendezvous control of space vehicles. In the 1960s, doctoral students who were trained in these sampled-data control system programs became the core of leading researchers in industry and education in the field of digital computer control.[9]

Atom Probe Field Ion Microscope (1953-1967)

The co-inventor of the Atom Probe Field Ion Microscope, Dr. Erwin Mueller, was a principal investigator for AFOSR from 1953 until his retirement from Pennsylvania State University in 1977. Prior to his arrival at Penn State in 1953, he had invented the Field Emission Electron Microscope (1936), and the Field Ion Microscope (1951), which was the first instrument employed to observe single atoms. In 1953, AFOSR issued two contracts with Dr. Mueller: one to refine the Field Emission Electron Microscope, and the other to develop an even more effective device: the Field Ion Emission Microscope, which was later termed the Atom Probe Field Ion Microscope. Invented in 1967, and commonly referred to as the atom probe microscope, this device is unlike optical or electron microscopes, because the magnification is the result of a highly curved electric field that removes ions from a sample surface in order to image and identify them. In successively sophisticated models, the instrument allows three-dimensional reconstruction of millions of atoms.[10]

Dr. Erwin Mueller, Atom Probe Field Ion Microscope

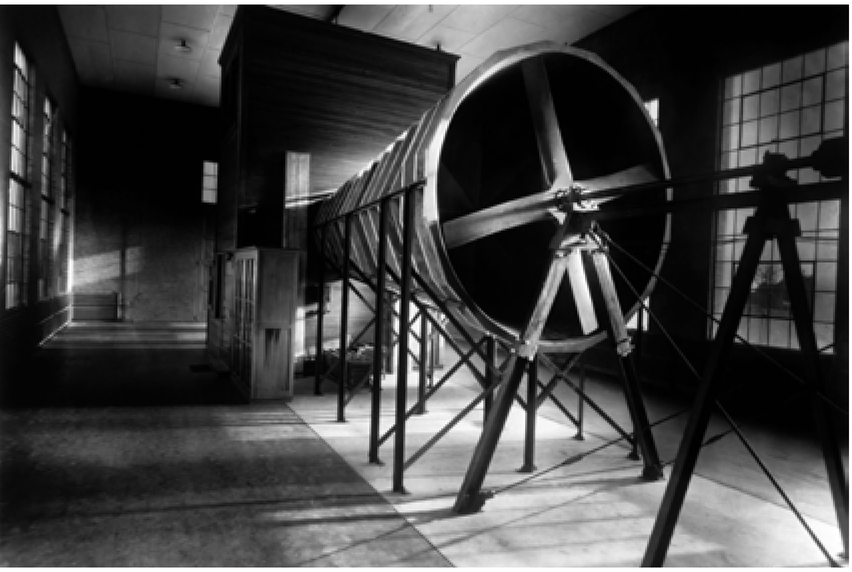




Magnetic Resonance: AFOSR Support for Advancing a New Approach to Chemical Analysis (1955)

One of the first researchers to explore the application of magnetic resonance to chemistry was Dr. John E. Wertz of the University of Minnesota. It was in 1953 that Dr. Wertz's program attracted the attention of AFOSR, where magnetic resonance, because of its broadening application at the time, was considered a significant scientific breakthrough. As such, AFOSR not only funded Dr. Wertz's research, but also asked him to write a comprehensive history and review of magnetic resonance applications. This was in line with AFOSR's mission to enhance and publicize techniques that would have a dynamic impact on research at large. Dr. Wertz's review, "Nuclear and Electronic Spin Magnetic Resonance," was published in 1955 and given worldwide distribution. Today, numerous magnetic resonance techniques are well known and widespread within every research community.[11]

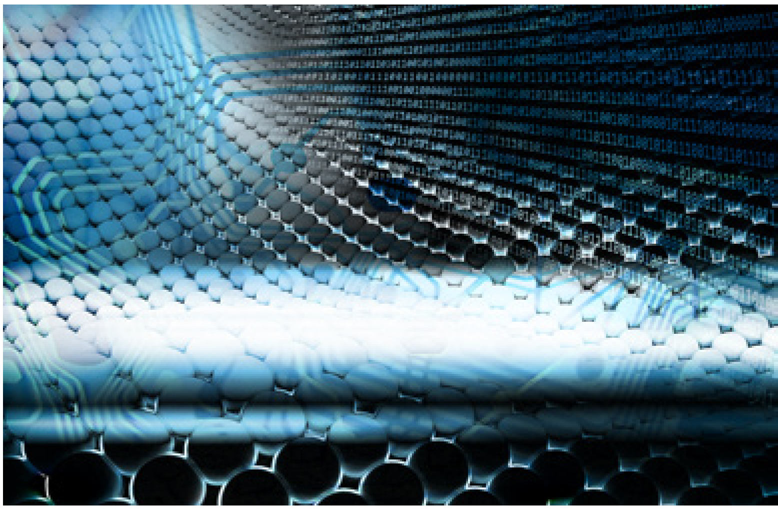
AFOSR: A Hypersonic Wind Tunnel Pioneer (1955-present)



AFOSR-funded research was critical for the development of our early space and missile program with regard to the development of long duration hypersonic wind tunnels that could adequately simulate low-altitude, high-velocity flight conditions. In the early 1950s the test requirements for ballistic missiles, space flight, and hypersonic flight far exceeded the capabilities of existing ground test facilities. To address this shortcoming, discussions between AFOSR and the Cornell Aeronautical Laboratory in 1955 resulted in the basic principles of the wave superheater. AFOSR contracted with Cornell in early 1956 to build a pilot model dubbed "Little Rollo," which confirmed that it was possible to make a true long-duration hypersonic wind tunnel in which test durations would be measured in seconds instead of milliseconds. In 1959, with the principle validated, the Advanced Research Projects Agency (now DARPA), supported the development of a full scale superheater facility "Big Rollo" at the Arnold Engineering Development Center. The full scale, wave superheater hypersonic tunnel became operational in 1962 at Arnold AFB, TN. Big Rollo was critical in the further development of various aviation, space, defense and industrial programs.[12]

Bose and Ray-Chaudhuri Error Correcting Codes (1958-1960)

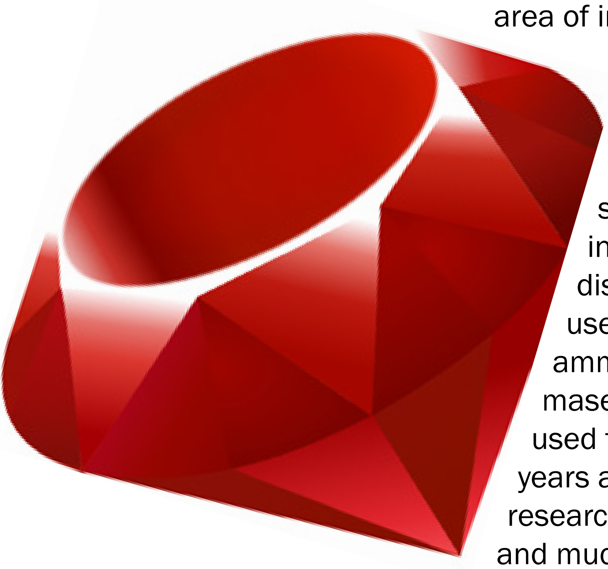
Since its establishment in 1951, AFOSR supported numerous research efforts to improve the quality of electronic communication--especially in the field of space communications. An AFOSR research contract (No. AF 49(638)-213) was issued in 1958 to Drs. R. C. Bose and D. K. Ray-Chaudhuri, of the University of North Carolina to look at utilizing error detection and correction to reduce the number of errors in a communication channel, as opposed to concentrating on increasing the signal-to-noise ratio. The result, published in 1960, was the establishment of a general theory of binary and K error correcting codes that when employed during code design, results in precise control over the number of symbol errors correctable by the code; it is possible to design binary codes that can correct multiple bit errors. Another advantage is the ease



with which they can be decoded, via a simple algebraic method, which permits the employment of unsophisticated low-power electronic hardware. It should be noted that Alexis Hocquenghem, a French mathematician, contemporaneously discovered and published this class of error correcting codes in 1959, independently of Bose and Ray-Chaudhuri, resulting in their designation as BCH codes, which today are used in applications such as satellite communications, compact disc players, DVDs, disk drives, solid-state drives and two-dimensional bar codes.[13]

Ruby Maser (1954)

At about the same time that Drs. Townes, Gordon and Zeiger were engaged in maser-related research, AFOSR also provided funding for Drs. Lyle Tiffany, Chihiro Kikuchi and other scientists at the University of Michigan's Willow Run Laboratory to perform basic research in the area of infrared detection (IR) equipment. Because of the pressure to produce an object of utilitarian hardware in what was known as "Project Michigan," they found it difficult to secure funding for a more detailed investigation into the more fundamental aspects of IR detection and turned to AFOSR. Using electron spin resonance techniques, they studied the defect structure in various crystals including the ruby. Almost incidentally they discovered that the ruby had properties that made it extremely useful in microwave amplification. Substituting a ruby crystal for the ammonia gas, their observations led to the development of the ruby maser, the first successful solid-state maser. Theodore Maiman later used the ruby as the basis for the first working laser in 1960. Five years after Maiman demonstrated his ruby laser, there were over 500 research groups in the United States engaged in laser development, and much of that research was based on a foundation and theoretical and experimental data arising from studies supported by AFOSR.[14]



Solid State Maser (1954-1960)

Nicolaas Bloembergen, who was initially funded by the Joint Services Electronics Program (JSEP), and later by AFOSR and the Office of Naval Research (ONR), conceived the first practical solid state maser in 1956.[15]

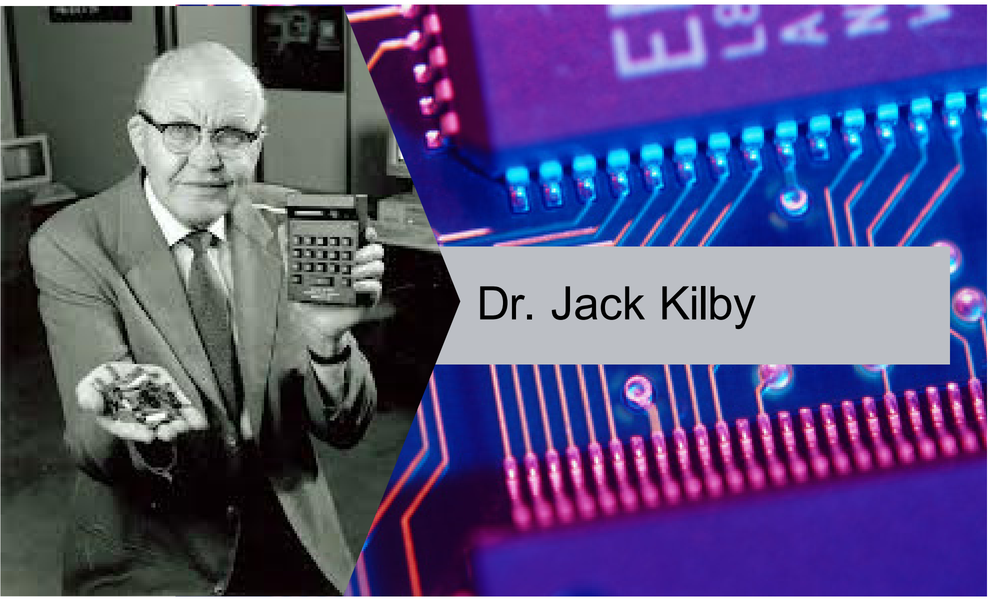
Kalman Filter (1958)

In the late 1950s, with the advent of the jet age and supersonic flight, AFOSR-sponsored various research efforts in the area of control theory related to high-speed aircraft, aerospace vehicle and advanced space systems. Designers of such systems needed to maintain aerodynamic integrity by deriving the "best" information from many data streams that contained imprecise data. A 1958 AFOSR research contract supported the work of Dr. Rudolph Kalman and Dr. Richard Bucy to investigate the use of modern mathematical statistical methods in estimation. Kalman and Bucy wrote several papers that ultimately led to the development of the Kalman filter which became a basic building block of flight. Almost all modern control systems--both military and commercial--use the Kalman filter. It guided the Apollo 11 lunar module to the moon's surface and will guide the next generation of aircraft as well.[16]

Electron Cyclotron Maser (1958)

AFOSR-funded work on the theory of electron cyclotron masers by Dr. Jurgen Schneider at Duke University in 1958 and 1959 was instrumental in the development of gyrotron oscillators in the 1980s which are used, for example, in material processing and plasma chemistry. The gyrotron employs a high magnetic field so that electrons circulate relativistically around the field at the desired frequency of the device, usually in the millimeter wave region. They are capable of higher power than other millimeter wave devices, and today are the key technology used in the recently deployed Active Denial System as a non-lethal weapon.[17]

Integrated Circuit (1958)

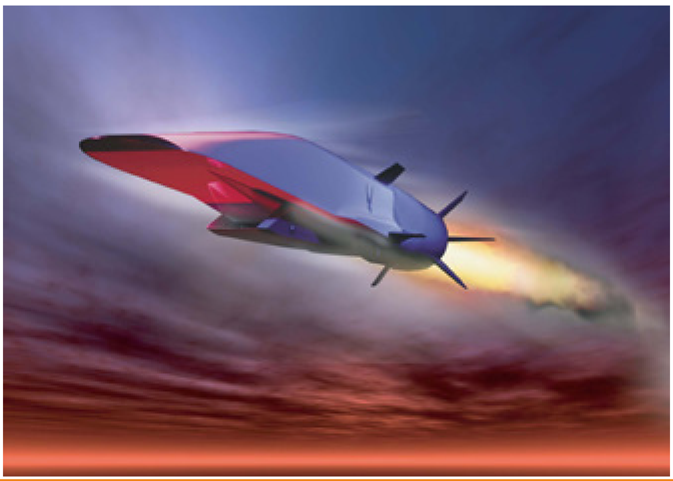


Dr. Jack Kilby

AFOSR was a pioneer in the theoretical and application work associated with the integrated circuit (IC). Various AFOSR-sponsored studies from 1950 through 1959 focused on molecular electronics. In 1958 and 1959, two Air Force scientists working at Wright Field secured AFOSR funding for Dr. Jack Kilby. In September 1958, Kilby demonstrated the first functional IC. In April 1959, this was followed by the first AFOSR contract with Westinghouse to study the application of molecular electronics to integrated circuits, and in June 1959, a similar contract was awarded to Texas Instruments. AFOSR was an early supporter and advocate for the application of semiconductor development for potential use in Air Force weapons systems. Kilby, who won the Nobel Prize for physics in 2000 for his invention of the IC, noted that early ballistic missile tests with integrated circuits largely assured the acceptance of semiconductor technology for other military and commercial uses.[18]

Early Supersonic Combustion Studies (1958-1965)

The design and capability of the current generation of hypersonic vehicles owes much to the efforts of AFOSR Program Managers to address the shortfall regarding experimental data on combustion in a supersonic airstream. The advantages of supersonic combustion for hypersonic air breathing engines include low static temperature in the engine, reduction of the dissociation of fuel and air molecules and increased recombination as the gases expand in the exhaust, and reduced diffuser losses. Beginning in 1957, AFOSR-funded select studies that approached the supersonic combustion issue from two points of view: shock-induced combustion and diffusional combustion. The most significant shock induced combustion AFOSR programs were at the Arnold Engineering Development Center at ARnold AFB, TN, which



concerned chemical reactions, aerodynamic effects, and measurements of static pressures when combustion mixtures, travelling at supersonic speeds, are passed through oblique shock waves. AFOSR-supported diffusional combustion research was conducted at the General Applied Science Laboratories (GASL), Ronkonkoma, NY, and dealt with the chemical and fluid dynamic phenomena that controls the supersonic combustion processes. The GASL experiments proved the possibility of extending ramjet capability beyond Mach 8 up to Mach 25.[19]

Programmed Instruction and the Armed Services Vocational Aptitude Battery (ASVAB) (1959)

Since 1959, AFOSR has funded and supported research and development of programmed instruction. This has given impetus to the field, not only for military training, but also in other sectors of American education. The USAF conducted much of the early work on designing programmed instruction and the means of evaluating its effectiveness with a select number of research programs funded by AFOSR. As a direct result of this activity, programmed instruction courses became commonplace in Air Force major commands during the 1960s. In fact, members of the Air Force engaged in these early programmed instruction efforts were responsible for establishing the National Society for Programmed Instruction, which stimulated further interest in this area. The AFOSR-funded programmed instruction research also had a direct impact on the other military services--all adopting the concept. In addition, industry and academic institutions were spurred on by the Air Force's interest in this area with the result that the process has become commonplace in corporations and schools.[20]

Integral Launch Reentry Vehicle (ILRV) Database (1955-1965)

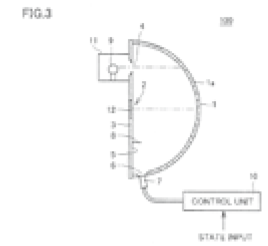
During the late 1950s and early 1960s, AFOSR-funded numerous hypersonic aerodynamics studies and supported the work of the USAF Aircraft Laboratory, and its follow-on the Flight Dynamics Laboratory, resulting in research that supported databases for the design of the first high speed X-planes such as the X-1, X-2, X-7, Alpha Draco, X-15 and Dyna-Soar and ultimately contributing to the integral launch re-entry configuration and analytical experimental database for a hypersonic lifting body—the space shuttle.[21]

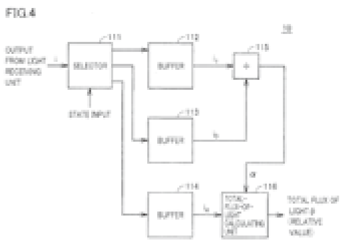
Attitude Stabilization of Satellites (1959-1963)

With the launch of Sputnik in October of 1957, a significant portion of the AFOSR program was shifted to satellite and space issues. One problem dealt with the ability to stabilize the attitude of a satellite without the necessity for internal power. Research at the University of Toronto under Dr. Bernard Etkin, and a follow on study by Dr. Hiroshi Maeda, at the University of Toronto while on leave from Kyoto University, resulted in an entirely new concept for such stabilization using the principle of gravity gradient. Long slender rods, specifically hinged to the satellite, achieve stabilization of the satellite in as little as one-third of an orbit.[22]

Early Biomimetics (1958-1964)

AFOSR was a pioneer in what is now termed biomimetics—the study of the structure and function of biological systems as models for the design and engineering of materials and machines. One of the very first biomimetic breakthroughs occurred through the efforts of AFOSR's European Office of Aerospace Research and Development whose funded research at the Karolinska Institute in Sweden resulted in the biological equivalent of lens coatings. This program found that the surface of the compound eye of certain insects and crustaceans is covered with geometrically spaced, dome shaped protuberances. These protuberances, because of their shape and spacing, efficiently reduce reflections from the surface of the eye, thus allowing the eye to capture more available light and see better in dim light. These protuberances on the eye serve the same function as man-made coatings, but are effective over a much broader range of wavelengths. Several large scale models of these projections, made of semiconducting material, were built to study the mechanism of this system with the use of microwaves. It was found that by varying the size and spacing of the projections, nearly all the microwaves can be reflected, thereby reducing the band of frequencies to a very narrow band.





This early research precipitated further endeavors towards the application of this discovery to optical and radio sensing devices and to the design of more sensitive and selective antennas.[23]

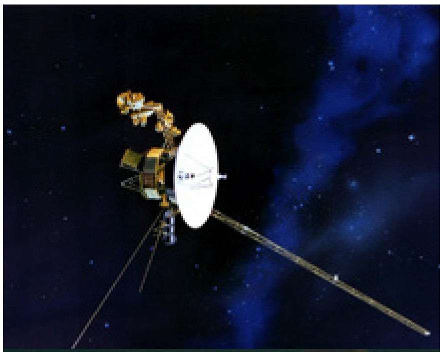
An Inexpensive Integrating Photometer (1959)

In 1959 an integrating photometer was developed by Drs. E. L. McGandy, J. Degelman, and K. Eriks under an AFOSR-funded program at Boston University. This instrument measures the difference between the light transmitted by an area of a film containing an image and the light transmitted by an equivalent area without an image. The difference is known as the "integrated intensity," thus the name, integrating photometer. This new photometer was remarkably accurate and comparable to the state of the art photometers of the time, with images of distorted shapes being more accurately measured than with any other known device. The price of the new photometer? One-quarter the cost of the photometer it replaced.[24]

Proton Beam Research (1954-1961)

The first suggestion that energetic protons could be an effective method for medical treatment was made in 1946 by a researcher at the Harvard Cyclotron Laboratory (HCL). The first treatments were performed with particle accelerators built for physics research, notably Berkeley Radiation Laboratory in 1954. This was followed by AFOSR-supported investigations at Sweden's Uppsala University Institute for Nuclear Chemistry, regarding the effect of irradiation by high energy proton beams on brain tissue, which helped lead to the refinement of proton beam therapy, whereby techniques were developed to target certain areas of the brain for irradiation. The most important application of the proton beam is its use as a microsurgical tool.[25]

1960's
AFOSR BASIC RESEARCH
SIX DECADES OF SUCCESS



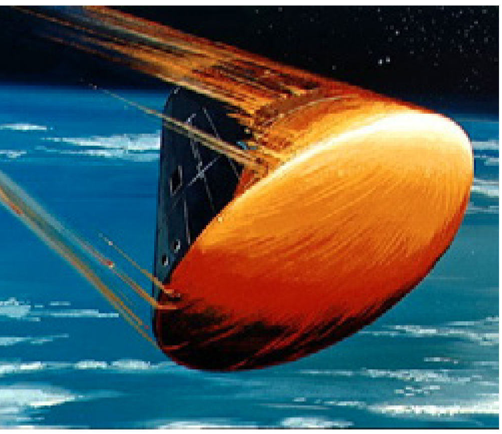
Reed-Solomon Coding (1960)

Reed–Solomon (non-binary cyclic error-correcting) codes were developed by Irving S. Reed and Gustave Solomon, at the MIT Lincoln Laboratory with support from AFOSR, the Office of Naval Research, and the Army Research Office. Their seminal article was entitled "Polynomial Codes over Certain Finite Fields." They described a systematic way of building codes that could detect and correct multiple random symbol errors. When the article was written, an efficient decoding algorithm was not known. It was in 1977 that R-S codes were implemented in the Voyager space program. The first commercial application appeared in 1982 with the compact disc. R-S codes found important applications from deep-space communication to consumer electronics. They are used in consumer electronics such as CDs, DVDs, and Blu-ray Discs, as well as in various data transmission technologies, broadcast systems, and computer applications.[26]

Rocket Casings: High Temperature Resistant Fibers (1960-1962)

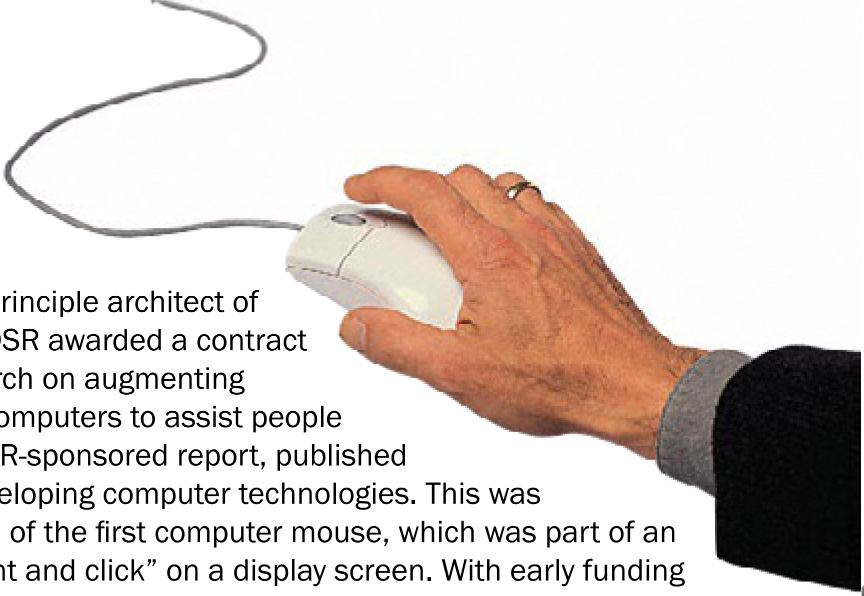
In the 1950s and early 1960s, AFOSR-funded numerous programs in support of space related materials. In particular, high temperature resistant surfaces applicable to space vehicles was a priority. In early research programs it was found that drawn materials, such as metallic "whiskers," are far stronger than normal metal, but that the metal fibers were easily deformed at high temperatures. This led to AFOSR-funded programs at the Bjorksten Research Laboratories in Madison, WI, that concentrated on the study of nonmetallic heat resistant quartz. Bjorksten devised a practical method for drawing continuous vitreous (glass-like) fibers from quartz. The angle of the fibers relative to the direction of the heat flux affected not only durability but also the transfer of heat. There was evidence to indicate that a thin coating of metal on fibers oriented at or near right angles to the direction of heat flux might improve the thermal protection properties of the composite for thermal shielding on nose cones and for nozzle construction in high-performance rockets. Ultimately, the Bjorksten work provided vitreous silica fibers of practically any length desired with melting temperatures of 2000° C and having an average tensile strength of up to 600,000 psi. The fibers were readily transitioned to make nose cone and rocket casings, and other applications where light- weight, strong, temperature-resistant material was required.[27]

Re-entry Vehicle Design and Rarefied Gas Aerodynamics (1960-1965)



One of the design problems of reentry vehicles is to assure that they are unstable in all but the nose-first attitude, where the heat shield is thickest. If a re-entry vehicle was capable of stable flight in some other attitude and reentered in that way, the heat shield would offer insufficient protection. One of the early model re-entry vehicles for ballistic missiles was designed to be unstable in all but the nose-first attitude in atmosphere of normal density. However, it was found that the vehicle was stable flying tail-first in rarefied gases. The company designing the vehicle found that AFOSR and the Office of Naval Research had sponsored previous research in rarefied gas thermodynamics at the University of California, Berkeley, with results directly applicable to this problem. The company redesigned the reentry vehicle, based on this research, so that it was no longer stable in the tail-first attitude, even in a rarefied gas flow.[28]

AFOSR and the Computer Revolution (1961)



AFOSR provided early support to the principle architect of the computer revolution. In 1961, AFOSR awarded a contract to Dr. Douglas Engelbart for his research on augmenting human intellect and the potential of computers to assist people in complex decision making. His AFOSR-sponsored report, published in 1962, served as a roadmap for developing computer technologies. This was followed in 1964 with the introduction of the first computer mouse, which was part of an experiment to find better ways to "point and click" on a display screen. With early funding for the inventor of the mouse and scores of computer-related innovations, Dr. Engelbart readily acknowledges the critical role that AFOSR played in support of the computer revolution.[29]

Aircraft Inlet Engine Flow Studies (1960s)

AFOSR-funded studies during the 1960s contributed significantly to the results of Project Tailor-Mate, a study of various aircraft fore-body shapes and their effects on engine-inlet flows. The Tailor-Mate inlet and airframe flow field research ultimately led to the successful design for the F-16 inlet.[30]

Wing-Body Blending (1960s)

As aircraft speeds increased, so did the need for more aerodynamic aircraft designs. AFOSR-funded research contributed to the ultimate designs of a new generation of fighter and bomber aircraft, in particular, the B-1 and F-16.[31]

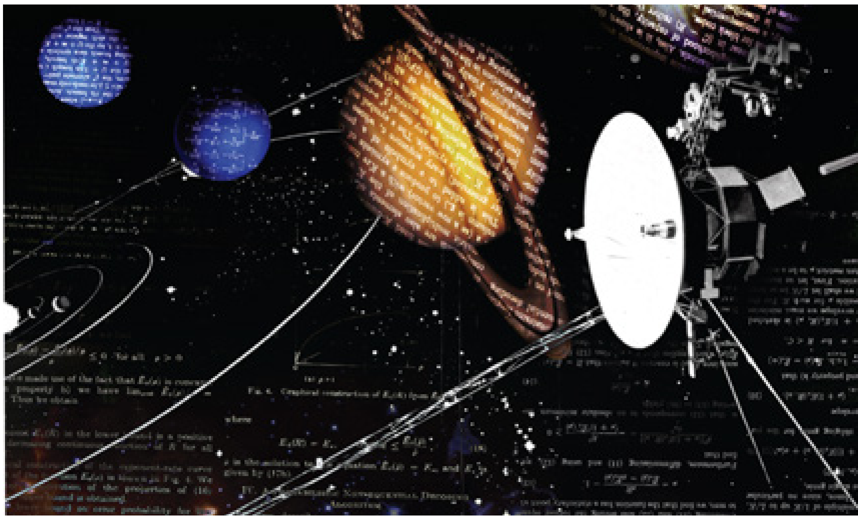
Flight Pressure Suit and Anti-Gravity Valve(1963-1975)

High performance aircraft flight would not be possible without pilots donning the now commonplace flight pressure suit with its integral anti-gravity valves. AFOSR-supported research on cardiovascular blood dynamics under G-stress provided the fundamental understanding of blood flow that was essential to their development. Without the basic research that led to the development of anti-gravity technology, pilots would not be able to withstand the high G forces involved in high performance aircraft maneuvering. This basic research was conducted at the University of Kentucky, the University of Texas, and the USAF School of Aerospace Medicine.[32]

1960's

Viterbi Decoding Algorithm (1965-1967)

Several years after the Kalman Filter algorithm was making its way into practical application, a revolutionary decoding algorithm was discovered by Dr. Andrew J. Viterbi while doing research support for AFOSR. This algorithm was first proposed in 1967 as a method for decoding convolutional codes. By the mid-1970s, Viterbi's algorithm was rapidly becoming the standard method for decoding in space communication systems. Viterbi's algorithm has become widely recognized as a solution to a variety of digital estimation problems, much as the Kalman Filter has been adapted to a variety of analog estimation problems. NASA employed the Viterbi decoding algorithm with great success in the Voyager flight to Jupiter and Saturn. It has been widely used in other military and civilian space programs including MILSTAR, DSCS, the Shuttle program and various commercial satellites. Over the years, Viterbi's algorithm has stimulated additional research and been applied to a number of technical areas including equalization in modems for time-varying channels, magnetic digital recording, and optical character reading. Viterbi and Dr. Kalman serve as excellent examples of the relevance of AFOSR-sponsored research as well as the prestige of the researchers.[33]



Global Positioning System (GPS) (1967-1990s)

A constellation of satellites that provides location and navigation aid, the Global Positioning System is used on a daily operational basis by all U.S. military services. It has become second nature as a tool in targeting, reconnaissance, and search and rescue operations. It has numerous commercial applications as well, such as land surveying, geodetic control, plate tectonic studies, and the ubiquitous automobile navigation system. AFOSR contributed in several critical ways to the GPS program. An early 1960s AFOSR research program resulted in the Code Division Multiple Access System (CDMA) that provided precise ranging and timing data, and allowed all satellites within a constellation to broadcast on the same frequency without interfering with each other. While operating under an AFOSR grant in 1967, Dr. Byron Knowles of Texas A&M University conceptualized a design for a low cost Global Positioning System. In 1973 the results of this GPS design were integrated with other system initiatives (Air Force System 621B, the Aerospace Corporation concept, and U.S. Navy systems, i.e., Transit and Timation), which eventually resulted in the NAVSTAR GPS program. It is significant to note that several other AFOSR programs were essential in making the GPS a viable system: Rudolf E. Kalman's filtering system permits the routines that determine GPS positioning to update system parameters and to zero in on the correct satellite range and azimuth; Charles Townes' maser work led to superior atomic clocks integral to the operation of every GPS satellite; additional GPS improvement came from Dr. Steven Chu, whose 1997 Nobel Prize in Physics was rooted in AFOSR program support. Dr. Chu's efforts to cool and trap atoms with laser light led to a 1000-fold increase in atomic clock accuracy. An improvement of that time standard has ripple effects throughout every precision physics area.[34]

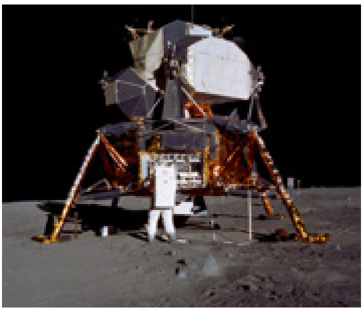
High Resolution Transmission (HITRAN) Database (1967)

An AFOSR-funded program resulted in the publication of the first atmospheric molecular absorption database which was used to optimize surveillance systems and electro-optic weapons. HITRAN is a compilation of spectroscopic parameters that a variety of computer codes use to predict and simulate the transmission and emission of light in the atmosphere; providing detailed knowledge of the infrared properties of the atmosphere. The original version was funded by AFOSR and compiled by the Air Force Cambridge Research Laboratories in the late 1960s. It is maintained and developed at the Harvard-Smithsonian Center for Astrophysics, Cambridge MA.[35]

Variable Geometry Wings (1960s-1970s)

AFOSR's aeromechanical funded research extended to variable geometry wing design as an outgrowth of its wing-body blending program and contributed to the wing designs of the Air Launched Cruise Missile and Ground Launched Cruise Missile.[36]

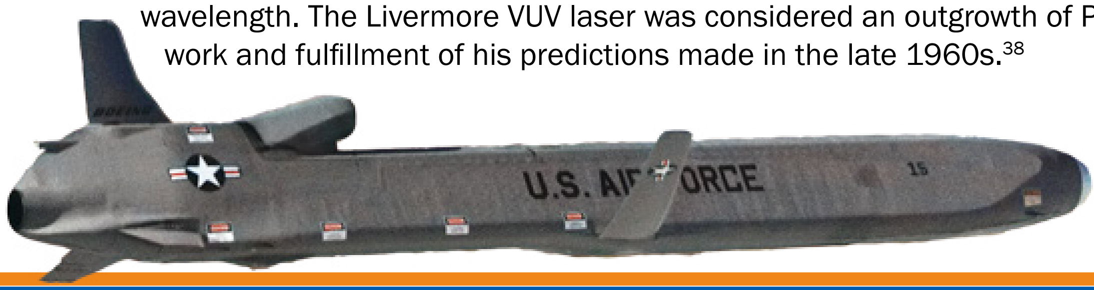
Optimization Theory (1962-1965)



In the early 1960s, AFOSR-sponsored research made significant contributions in optimization techniques based on the theory of variational calculus. This research made it possible to obtain numerical solutions to several prominent aerospace problems. In addition to its numerical use, the theory provided a guidance control law for maintenance of an optimum trajectory by a space vehicle in the presence of random disturbances. The theory was used to calculate optimum ascent, descent, and abort trajectories for the Apollo Lunar Excursion Module as well as circumlunar Earth-to-Mars trajectories.[37]

Ultraviolet Laser Experiments (1965-present)

Early work in the rare gas dimers (including especially Nicolay Basov in the U.S.S.R.) led to the rare gas halide excimer lasers of enormous importance today, in lithography for microelectronics (where AFOSR had an important role), in laser vision correction, and many other areas. Research interest in vacuum ultraviolet (VUV) continuum emission from noble elements developed as a result of the potential these elements had for high-power lasing. Experiments at the Livermore Laboratories in California revealed stimulated emission in the VUV from high-pressure xenon gas excited by high-current relativistic electron beams. Working with AFOSR support as far back as 1965, Professor Stuart A. Rice of the University of Chicago reported that research with the gases neon, argon, krypton, and xenon, in their liquid state, resulted in the formation of excited dimers, and that emission from the liquid and the solid came from these dimers. He had shown that excited dimers were formed in many polymers, suggesting that these systems were also potential candidates for laser development. Because polymers and other aromatic systems could be "tuned" by chemical substitution, there existed, in principle, the possibility of making lasers covering a broad range of wavelength. The Livermore VUV laser was considered an outgrowth of Professor Rice's original work and fulfillment of his predictions made in the late 1960s.[38]



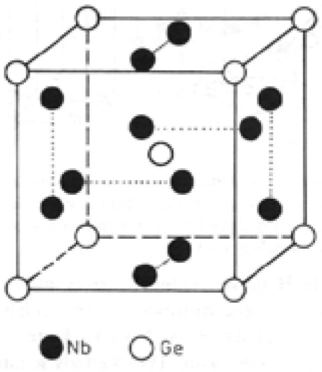
New Software Company Based on AFOSR-Sponsored Research (1965-1993)

With long-term AFOSR support from 1965 to 1993, Professor Michael Dewar of the University of Texas developed a novel approach to computational chemistry. Professor Dewar's method allows the theoretical prediction of chemical reactions and reaction mechanisms to be used as practical adjuncts to experimental procedures. It allows researchers to better predict molecular structure and properties and optimize their chemical synthesis processes, resulting in better materials and lower production costs. Prior to receiving AFOSR support, several funding agencies rejected Dewar's proposals as too radical, but his semi-empirical method eventually gained wide acceptance and popularity throughout the defense, commercial and industrial communities, After Dewar's retirement in 1993, Professor Andrew Holder of the University of Missouri, Kansas City, began to build on Dewar's accomplishments to advance this technology, with AFOSR support. With Dewar's urging, he created a company named Semichem to commercialize the software based on semiemperical computational chemistry. Semichem remains in business to this day.[39]

Rare-Earth Magnets (1962-1972)

A significant AFOSR success story concerns the research related to Cobalt Rare Earth Magnets (CoRE)–a dramatic improvement in permanent magnet materials. The Air Force, as well as aerospace manufacturers, had been deeply involved with CoRE for some time. In particular, AFOSR-funded two individuals who contributed to this effort. Critical to this research was Dr. Karl Strnat, a researcher at the U.S. Air Force Materials Laboratory at Wright Patterson Air Force Base in the 1960s and 1970s. With AFOSR support, Strnat discovered a new, improved class of magnets, samarium cobalt rare earth magnets. He not only discovered the high energy product (18 MGOe) of the Samarium-Cobalt (SmCo5) compound in 1966, but in 1972, along with Dr. Alden Ray, was responsible for Advanced Rare-Earth Magnets, developing a higher energy product (30 MGOe) Samarium-Cobalt (Sm2Co17) compound. The resulting Strnat Company in Dayton, Ohio, is still in the magnetic materials business. In addition, Dr. A. J. Freeman of the Materials Research Center, Northwestern University, a leading theorist in magnetic materials, had been supported by AFOSR beginning in 1970. His research contribution was an effective computer model for alloys of cobalt with various proportions of rare earth metals to accentuate the desired electrical and magnetic properties of this class of alloys. The contributions of Strnat and Freeman, plus the efforts of several researchers at the University of Dayton, sponsored by the Air Force Materials Laboratory, resulted in an alloy of Samarium and Cobalt that produced permanent magnets of at least twice the power (with one-half the weight) of any other known materials. At the same time, these magnets were much more resistant to becoming demagnetized, and were able to operate at higher temperatures. These properties combined to produce a wide spectrum of applications, some of which were not possible with conventional materials. Applying the new magnets to jet engine tachometer drive units improved their service life from 100 hours to more than 2,000 hours. The General Electric corporation also produced a family of new Traveling Wave Tubes for use in electronic countermeasure systems. The new magnets permitted new designs with less material resulting in even greater weight saving. Electrical starters for jet engines were impractical because of the high voltage drop through the starter motor which resulted in a severe burn-out problem. The strength of the new magnets permitted a design with permanent magnets in either the rotor or stator—which reduced the voltage drop by one-half and opened up the possibility of electrical starting systems for jet engines. Used in aircraft power generation systems, these magnets opened up the possibility of eliminating the complex and troublesome constant speed drive by substituting a power conditioning package. Also, using such powerful permanent magnets made it possible to build the power generator and the starting motor in the same unit, with further significant weight savings. Small electric motors designed with these magnets produced efficiencies of the order of 70 percent compared to 40 percent for conventional motors. This savings, together with the other characteristics previously listed, prompted one manufacturer to bring out a new line of cordless portable hand-held power tools using CoRE permanent magnets.[40]

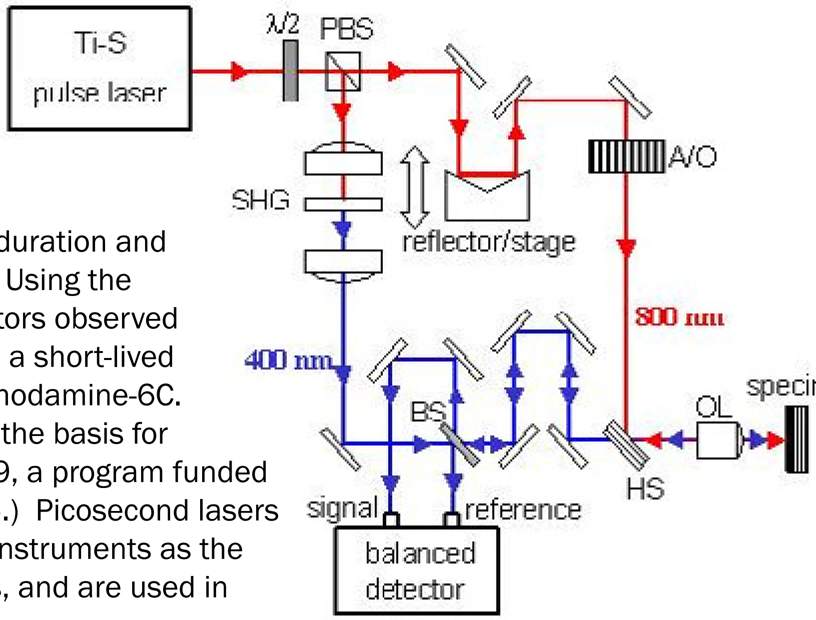
Niobium Germanium (Nb3Ge)–23K Superconductivity (1967-1974)



With AFOSR sponsorship, Niobium Germanium (Nb3Ge) was discovered to be a superconductor in 1973, and for 13 years (until the discovery in 1986 of the cuprate superconductors) it held the record as having the highest critical temperature. Primary investigators D. W. Deis, John R. Gavaler, and W. T. Reynolds, published their findings in June 1974 in AFOSR Technical Report 74-0989, while working at Westinghouse Research Labs., Pittsburgh, Pa. In an April 2012 IEEE/CSC & ESAS European Superconductivity News Forum article, on the history of superconductivity research at Westinghouse, AFOSR was singled out for its support in this area. The authors noted that: “Special credit is also due to one government agency, the AFOSR. Since the late 1960s it maintained continuity of support for the relatively fundamental work in materials – until the group was sold to Northrop Grumman and even beyond. This was due to the long-term vision of the late Program Director Max Swerdlow (1915 - 1989) and his successor Harold Weinstock.”[41]

AFOSR: Pioneering Support for Picosecond Photochemistry (1968-present)

With AFOSR funding, techniques and instrumentation were developed for observing the excited states of molecules with nanosecond to picosecond time resolution (10-12 seconds). As a result it became possible to observe broad-band absorption spectra in the time scale of electron and proton transfer processes. The observation of short-lived absorption of light photons by excited molecular states was of importance in understanding the dynamics of laser control materials such as those for Q-switching and modelocking. Researchers at TRW Systems Group previously used a Q-switched ruby laser and a laser-induced spark to observe excited singlet states of aromatic compounds on a nanosecond time scale. They extended the time resolution of laser photolysis into the picosecond range by using the second harmonic (530 nm) of a modelocked neodymium glass laser as an excitation source. The broad-band monitoring source was the self-phase modulation continuum produced when 530nm picosecond laser pulses were focused into glass, water, and other optical media. Continuum pulses of picosecond duration and band width of 320 nm to 700nm were obtained. Using the continuum as a monitoring source, the investigators observed inverse Raman spectra in several molecules and a short-lived transient absorption in the dye laser molecule Rhodamine-6C. Picosecond photochemical measurements were the basis for Ahmed Zewail’s Nobel Prize in Chemistry in 1999, a program funded solely by AFOSR beginning in 1986 (see page 45.) Picosecond lasers have evolved into femtosecond and attosecond instruments as the lasers have produced shorter and shorter pulses, and are used in photochemistry and photophysics applications.[42]



1970's

AFOSR BASIC RESEARCH

SIX DECADES OF SUCCESS

Dynamic Photo-Multiplier (1962-1963)

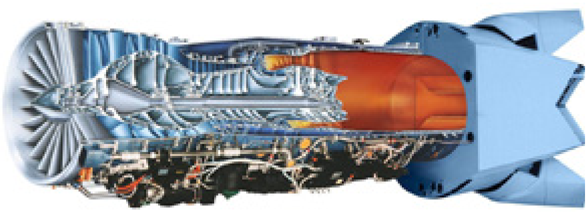
In 1962 and 1963, AFOSR-funded research at the University of Illinois, Urbana, resulted in a new device for detecting and amplifying low-level, ultra-high-frequency light waves. The "secondary emission electron multiplication system" (Dynamic Photo-Multiplier), performed tasks in the high-frequency light ranges that were previously performed by photo-multipliers only in the low-frequency light ranges. The Dynamic Photo-Multiplier went on to become a highly efficient, low-level-light, low-noise detection tool for use in radio astronomy, radar, and optical communications, as well as basic research.[43]

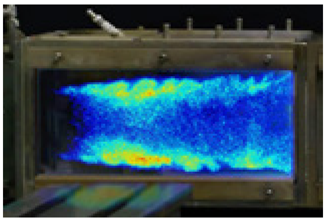
Titanium Aluminides Research (1970-present)

One of the most promising intermetallic materials for application in aircraft engines has been gamma titanium aluminide (TiAl). This material has many positive properties lending itself to engine use, such as high stiffness, high strength, high-temperature oxidation stability, and creep resistance. It is also 50% lighter than the superalloys currently used in aircraft engines. One area of concern was the material's lack of ductility—the ability to deform before failure—leading to cracking without warning. Since 1970, AFOSR supported research at four universities and six companies to study TiAl microstructure, processing, and design to determine its practicality in aircraft engine components. One of these companies demonstrated that adding niobium promotes more beneficial deformation and stabilizes the ductile beta-phase. This enhances the fracture toughness of the material by up to a factor of four. Beginning in 2000 various TiAl alloys have made their way into aircraft and automobile applications. Gamma TiAl has been applied to most applications due to exceptional mechanical properties as well as oxidation and corrosion resistance at elevated temperatures, making it a prime candidate as a replacement for traditional Ni based superalloy components in aircraft turbine engines. Low pressure turbine blades and high pressure compressor blades, traditionally made of an Ni based alloy, are twice as dense as TiAl based alloys. As such, use of TiAl components greatly enhances the thrust-to-weight ratio of an aircraft engine. General Electric uses TiAl low pressure blades on its new GEnx engine for the Boeing 787 and 747-8 aircraft.[44]

Light Scattering Spectroscopy (1970-present)

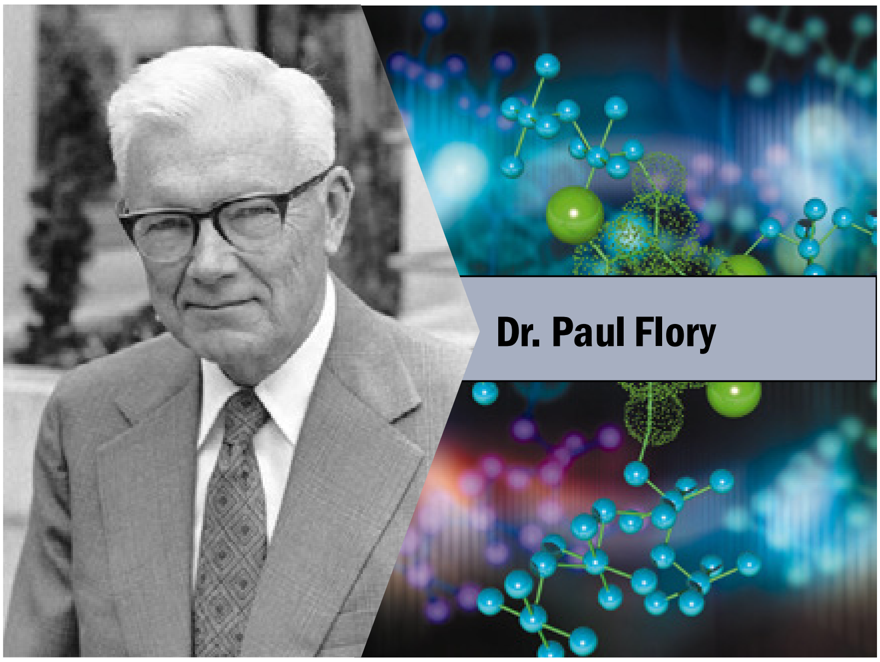
With the advent of laser light sources, light scattering spectroscopic diagnostic techniques assumed an ever-increasing role in a broad spectrum of physical investigations. Of particular importance was the potential application of laser spectroscopy to the hostile, yet sensitive, environments characteristic of those in which combustion occurred. These diagnostic techniques should facilitate greatly improved understanding of a variety of combustion processes which, in turn, should lead to enhanced efficiencies and cleanliness in energy, propulsion, and waste disposal systems. Experimental demonstrations of the potential of a variety of Raman processes (spontaneous, near-resonant, coherent, stimulated) and laser fluorescence techniques appeared in studies dealing primarily with laboratory flames. AFOSR has supported research in the fields of Raman spectroscopy, surface enhanced Raman Spectroscopy (SERS), coherent Raman anti-Stokes



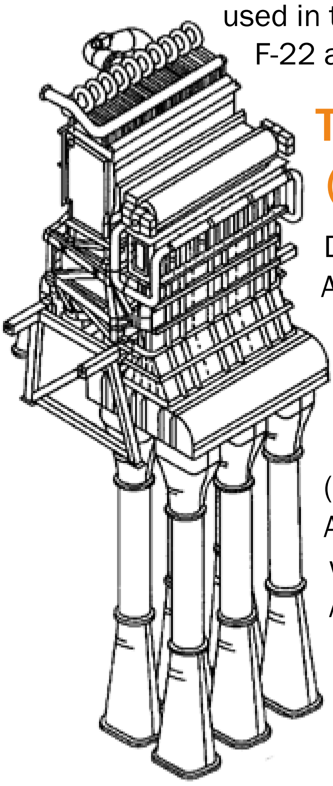


spectroscopy (CARS) and microscopy. A particularly noteworthy example is Dr. James Gord's work at the AFRL Propulsion Directorate on femtosecond CARS for combustion diagnostics. In one AFOSR-funded program, Gord employed ultrafast lasers for high-definition, four dimensional spectroscopic metrology techniques for investigating the physics and chemistry of reacting flows in jet engines. His approach resulted in high quality data for advanced concept development and model validation (R&D), propulsion-system performance assessment (T&E), and weapon-system active combustion control (ACC).[45]

Paul Flory: 1974 Nobel Prize in Chemistry



The 1974 Nobel Prize in Chemistry was solely awarded to Professor Paul J. Flory of Stanford University for his research on modes of formation and structure of polymeric substances. His research had been almost totally supported by AFOSR since 1961. Dr. Flory's initial research focused mainly on photochemistry and spectroscopy, which enables scientists to determine the composition of molecules by analyzing the light they emit when heated. Later, Flory began researching the physical chemistry of polymers. He studied their properties in solution and in bulk, and his research revealed the connections between the chemical structures of the individual polymer molecules and their physical properties. Considered by many to be the "founder of polymer science," Flory's work with nylon and synthetic rubber proved to be of great commercial importance. Dr. Flory developed the framework to understand the physics and viscoelasticity behavior of polymers. This framework led to the development of advanced resins used in organic-matrix, carbon-fiber reinforced composites currently used in the wings and fuselages of many Air Force aircraft, including the F-16, B-2, F-22 and Joint Strike Fighter (JSF).[46]



The Chemical Oxygen-Iodine Laser (COIL) (1975-1977)

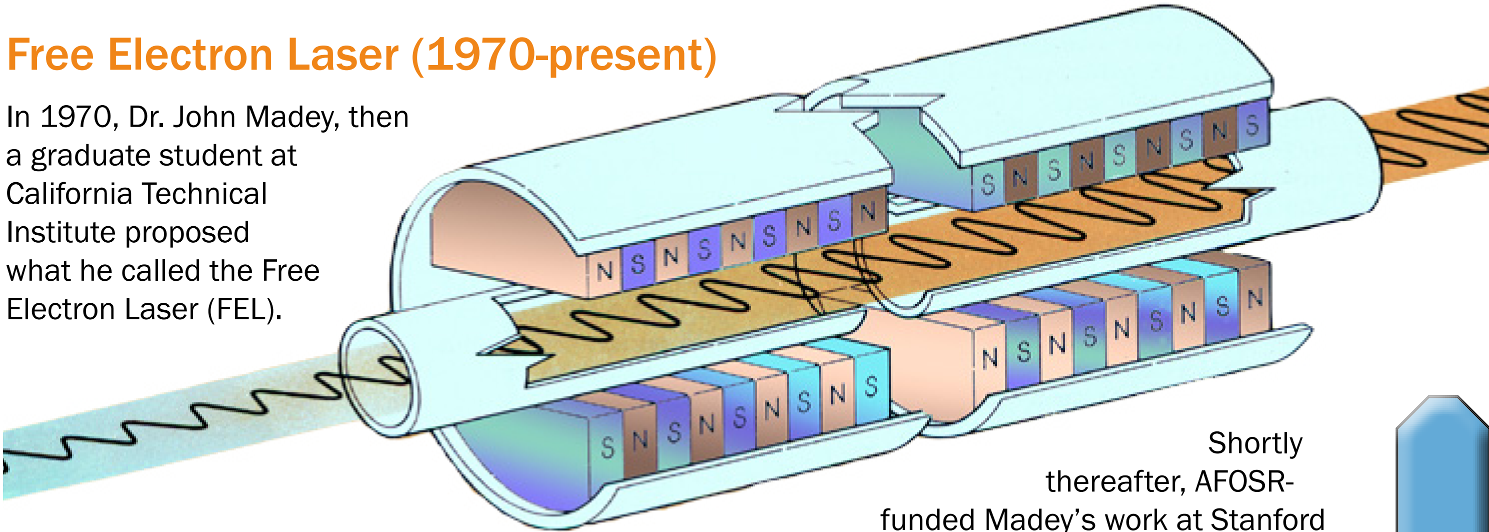
Due to the early funding of Dr. Charles Townes' maser and laser work by AFOSR, there is a direct link between the maser and laser basic research in the 1950s and the evolutionary laser technology developed by AFOSR-funded research for the Air Force's Airborne Laser (ABL). In 1977, two active duty United States Air Force officers, Captains William E. McDermott and Nicholas R. Pechelkin, sponsored by AFOSR, invented the chemical oxygen-iodine laser (COIL) at the Air Force Weapons Laboratory (AFWL), a predecessor unit to the Air Force Research Laboratories' Directed Energy Directorate. COIL was refined with additional AFOSR basic research funding. As the potential of COIL grew, AFOSR funding support enabled and improved all related ABL development and witnessed significant advances in atmospheric compensation and correction (1985); vibration elimination (1988); and research for the new All Gas Iodine Laser (AGIL).[47]

Model of Chemical Laser Processes (1970-1972)

In the early 1970s a classical theoretical model of molecular collision processes provided important information to designers of advanced chemical lasers. The model was developed by H. K. Shin of the University of Nevada with AFOSR support, and described energy transfer processes involving excited hydrogen halides (hydrogen fluoride and deuterium fluoride). The model used classical theories to predict temperature effects on vibrational energy relaxation rates using assumptions of ideal dipoles, rigid rotator molecules, and strong attractive interaction forces. The theory was in agreement with experimental results obtained by the Air Force Weapons Laboratory (AFWL) and other AFOSR researchers.[48]

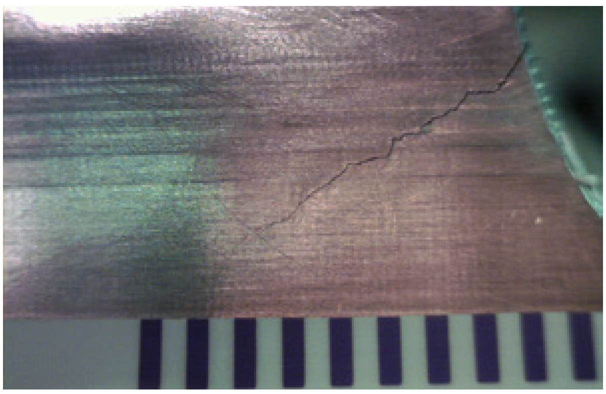
Free Electron Laser (1970-present)

In 1970, Dr. John Madey, then a graduate student at California Technical Institute proposed what he called the Free Electron Laser (FEL).



Shortly thereafter, AFOSR-funded Madey's work at Stanford University with the goal of developing the first operational FEL, which was demonstrated in 1975. FEL's are fundamentally different from other lasers, and more like microwave amplifiers, in that they use beams of electrons to supply gain. They can be tuned to any wavelength, from hard x-rays to microwaves, by changing the beam energy. They are capable of extremely high power and, because the beam energy can be recovered, very high efficiency. These characteristics make the FEL important for a wide range of research, industrial, and defense applications; it was studied extensively for possible employment by the Strategic Defense Initiative program in the 1980s. The FEL is used today in a variety of medical applications. (See Medical Free Electron Laser, p. 41)[49]

Fracture Mechanics Methodology (1970-1975)



With AFOSR funding, the development of a fracture mechanics methodology has resulted in the accurate prediction of crack growth rates in metallic structures. It has been a key technology for extending aircraft life under the Air Force's aircraft structural integrity program. Knowledge of crack growth rates is a key determinant in establishing the appropriate inspection intervals for airframes, resulting in preventive maintenance and best use of maintenance personnel.[50]

AFOSR and Superplastic Forming: A Revolution In Aerospace Material Science (1976-1982)

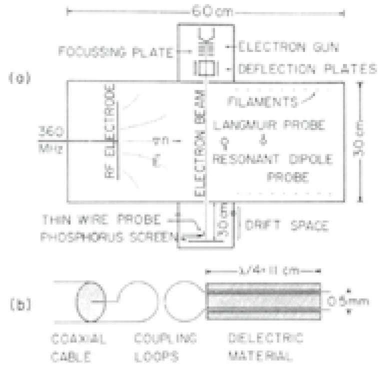
AFOSR has sponsored an active research portfolio concerning "aircraft structures and materials" from the day it was first chartered. One program initiative was the superplastic forming (SPF) of aluminum, titanium, and nickel alloys for aircraft structure components. The superplastic process allows the production of larger complex shapes with a minimum of tooling and machining. The SPF program was due in large measure to AFOSR Program Manager Dr. Alan H. Rosenstein, whose objective was to investigate the influence of aluminum alloy grain size on mechanical properties with respect to airframe applications and its potential for being superplastically formed, whereby, in this case, aluminum can exhibit deformation strains exceeding 1000 percent during the manufacturing process. The result is a dramatic reduction in manufacturing and maintenance costs due to a significant reduction in body parts and related fasteners per aircraft. Rosenstein's programs resulted in the production of bulkheads for T-39 trainer aircraft at a cost savings of 36% and with a weight savings of 22%. In the case of the T-39, the conventionally riveted bulkhead construction process contained 18 separate parts and 187 fasteners, while the SPF component contained only five separate parts and 20 fasteners. The superplastically formed structural process was also applied to the U.S. Army's AH-64 Apache helicopter. But the most striking and revolutionary application of the process were the many advantages that were realized when the process was applied to the construction of the F-15E duel role fighter. The aft fuselage of early generation F-15s were manufactured with conventional forming and machining methods, i.e., a sheet metal assembly process. The F-15E was largely produced by superplastic forming and diffusion bonding processes. SPF is combined with diffusion bonding wherein parts are held in intimate contact during the high-temperature forming process, allowing a high-integrity bond to form because of inter-diffusion across the interface. The result was a unitized and much stiffened airframe construction process that not only resulted in a much stronger aircraft, but the SPF process also eliminated 726 parts, 10,000 fasteners, and the concurrent elimination of the requisite manufacturing hours related to those many parts. Another valuable bonus was the realization of an additional ten cubic feet of equipment space for the F-15E. Cost savings alone for the F-15 program was substantial. The F-22 and F-35 fighter aircraft, as well as wide-body commercial planes such as the DC-10, Boeing models 747, 757, 767 and the McDonnell Douglas MD-11 have also benefited from superplastically produced components.[51]

Infra-Red Sensors: Improving Aircraft Targeting Effectiveness (1973-2000)

The Infra-Red (IR) imaging and signal processing effort is an excellent example of a long-term and very complex transition path that started with AFOSR-funded basic research in 1973 for studies in Barrier Emission Physics, followed by AFOSR-funded studies in metal-silicide detectors and sensor models relating to noise theory, up through 1983. These efforts also included exploring options related to reducing the cost of IR imaging technology. The initial results were transitioned to Air Force laboratories and industry as early as 1978 and fed into sensor component and material designs that eventually led to systems delivered to the warfighter in the late 1990s and early 2000s. AFOSR research resulted in a new generation of sensor concepts, devices and transitions to DoD and industry in areas such as: an all-silicon IR camera based on Platinum Silicide (PtSi); the first practical IR starting-mode imager; and the first useful thermal imaging in the mid-wave IR band. Applications were significant. The PtSi based IR Focal Plane Array camera was installed on 94 B-52H aircraft in 1998 and provided a 100-fold increase in

reliability, a three-fold decrease in cost, and a three-fold increase in viewing range. The estimated cost savings compared to the system it replaced: approximately $62 million. This technology was also employed in the U-2 and the Predator. The PtSi transitional history is a prime example of how patient support of basic research can result in significant military products and capabilities.[52]

Caviton (1970-1974)



With funding from AFOSR, UCLA professor Alfred Y. Wong, discovered the caviton, a new type of plasma instability that is both fundamental in nature, and has direct application to practical matters, such as nuclear weapons simulators and fusion reactors for large scale energy production. This discovery was considered by the American Institute of Physics as one of the three most important advances in plasma physics in 1974. The caviton is a "parametric" instability, where a modest electromagnetic wave that is injected into a plasma, resonates with the charged particles within the plasma to gently convert the modest input energy into large scale plasma waves where the high-density plasma is surrounded by a low-density plasma trough. The physics of this process is mathematically similar to a child on a swing who systematically goes higher and higher into the air by rhythmically kicking their legs. Much as the modest leg kicks result in a large swing into the air, the caviton has very large density modulation despite only mild input energy of the electromagnetic waves. Cavitons have appeared naturally in the ionosphere driven by the modest electromagnetic waves from lightening, resulting in large scale plasma structures that can impact aurora formation and the reception of radio waves and GPS signals around the world. More down to earth, the caviton phenomenon has been exploited in laboratory settings to develop high-amplitude currents of charged particles which can be used to generate x-rays to simulate the effects from nuclear weapons. This enabled facilities for testing electronics for survivability in harsh nuclear and space environments. Based on these applications, the caviton also found application in the development of fusion schemes for large-scale, clean/green power production from fusion, where the high-density plasma waves were used directly to drive fusion fuel to thermonuclear conditions for the production of power, although the coupling of energy to the fusion fuel is limited in practice. Despite these challenges, the caviton remains a signal example of the collective behavior that exists in plasmas.[53]

Biological Reduction of Toxic Phenolic Wastes and Ammonium Perchlorate (1970-1991)

AFOSR has been instrumental in solving the environmental challenges regarding the treatment of two environmentally hazardous materials: phenolic wastes and ammonium perchlorate. Phenols were employed in many Air Force industrial operations including stripping of paint from aircraft, but no known chemical or mechanical system was developed for the degradation or breakdown of the resulting high concentrations of phenolic wastes. In 1970, AFOSR, looking to resolve this issue, funded Dr. Howell Cobb and his team at Trinity University, and they ultimately identified 19 strains of bacteria capable of degrading cresol in concentrations of 900 parts per million (ppm) and one strain of bacteria which thrived at 1400 ppm. A pilot plant operation, utilizing optimal temperature and hydrogen ion concentration was completed. Results suggested that through proper maintenance of the influent, rapid and complete degradation of the high concentrations of cresol would be possible. Engineers at the Air Force Environmental Health Laboratory, Kelly Air Force Base, Texas, assisted in the monitoring of this

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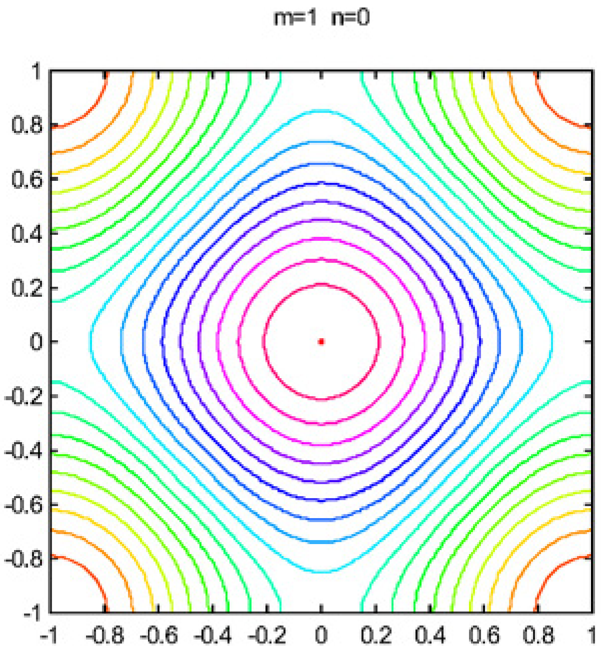
research effort. A more recent environmental initiative resulted in a successful system for the treatment of ammonium perchlorate, an essential component of solid rocket fuel. In the late 1980s, this requirement became acute with the refurbishment requirements of the ICBM fleet, whereby the ammonium perchlorate required conversion to an innocuous product. In 1989, three Air Force scientists at the Air Force Engineering and Services Center at Tyndall AFB, Florida, discovered a microorganism that apparently converted the perchlorate ion to a chloride, or simple salt, under extremely mild conditions. This led AFOSR to fund further investigation of their effort from 1989 to 1991, to confirm and scale-up their conversion process. The investigation's success prompted the Air Force to provide advanced development funding, ultimately resulting in a patented full scale biological reactor system that has been licensed to industry.[54]

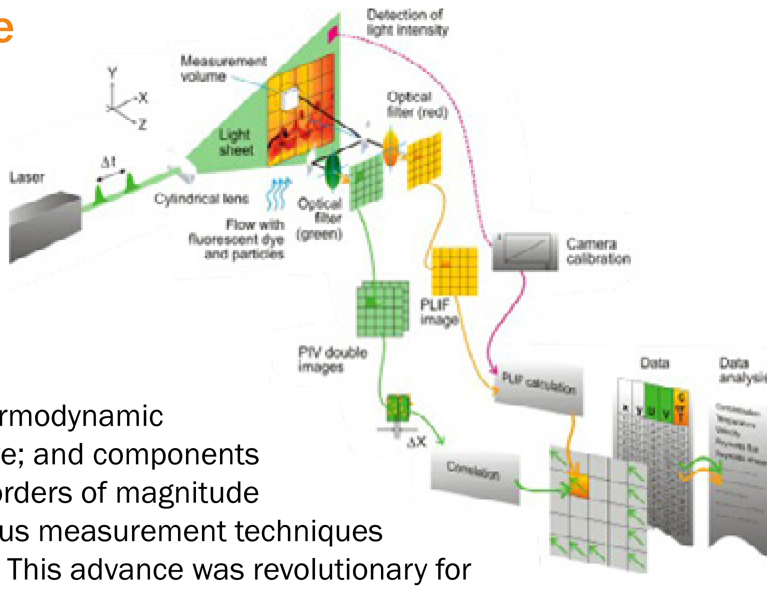
Brilliant Points: The Most-Cited Technical Publication Ever Written with AFOSR Support (1970-1975)



During the early 1970's, primary investigators Frank Harris and Hendrik Monkhorst, at the University of Utah, were jointly funded by AFOSR to carry out basic research on computational techniques for studying the electronic properties of solids. This topic was of importance because the knowledge that might be thereby gained could help in the design of advanced materials, and could also contribute to the understanding of a wide variety of basic scientific phenomena. At this time, computers had not yet become sufficiently powerful to permit straightforward study of systems of macroscopic extent (e.g., solids), and it was customary to proceed by rather crude approximation methods. Harris and Monkhorst had developed, and were in the process of implementing, methods that were more firmly rooted in basic science (and that are now in use throughout the world), but they faced what seemed to be a simple technical problem: A more efficient method was needed for sampling the computed data for sets of points that were representative of the entire electronic structure of the crystalline solid. Jim Pack, then a graduate student in the PIs' group at the University of Utah, was assigned to work on this problem. Before long he had reported that the sampling efficiency depended crucially upon the locations of the sampling points, and that it was important that they avoid, as much as possible, points in the crystal that were of high symmetry. This notion, which appeared not to have been previously recognized, was refined and quantified, and the results were reported to the scientific community in a paper entitled "Special Points for Brillouin-Zone Integrations", with H. J. Monkhorst and J. D. Pack as authors, published in Phys. Rev. B (vol. 13, pp 5188ff, in 1976). The publication of this paper was not without controversy; it was objected to by the authors of an earlier paper who disagreed with its conclusions. The editors of Physical Review B resolved the matter by publishing the paper and in a later issue accepting a comment and rebuttal. None of those involved could have predicted it at the time, but this computational insight turned out to be of nearly universal importance in condensed-mattter computations. AFOSR's support of a relatively obscure topic in computational physics was found to have produced a tool that has now become an integral part of many thousands of computations on a variety of crystalline materials. This story is of particular interest regarding the history of AFOSR, because the above-cited paper by Monkhorst and Pack has now become one of the 13 most-cited articles in the entire history of the American Physical Society journals, and it appears to be the most-cited technical publication ever written with AFOSR support. As of late 2012, the paper had been cited 13,000 times in the 36 years since its publication, with an average of five additional citations still occurring daily.


1980's
AFOSR BASIC RESEARCH
SIX DECADES OF SUCCESS

Planar Laser-Induced Fluorescence (PLIF) (1980-1986)

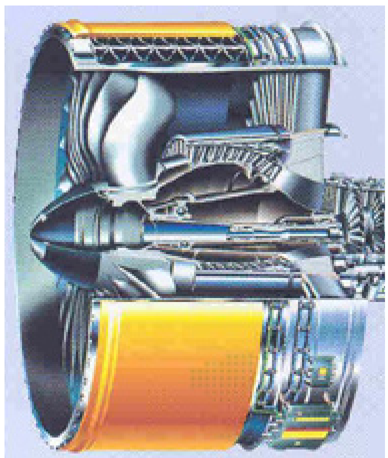


PLIF is an optical diagnostic technique widely used for flow visualization and quantitative measurements such as velocity, concentration, temperature and pressure. The successful goal of this AFOSR-funded Stanford University program was to produce time-resolved quantitative information in two and three dimensions for intermediate species such as oxides of nitrogen; thermodynamic quantities such as pressure, density and temperature; and components of fluid velocity. The PLIF program resulted in many orders of magnitude improvement in data acquisition compared to previous measurement techniques based on single-purpose electro-mechanical probes. This advance was revolutionary for hypersonic vehicle measurements as flight tests can be prohibitively expensive and ground testing is limited to milliseconds of useful test time. This technique is used extensively by DoD laboratories, and NASA as well as the automotive industry for research and testing of engines.[55]

Major Improvement Made in Semiconductor Structures: Low Temperature Gallium Arsenide (1982-1985)

In 1985, under an AFOSR-funded program, a team from the University of Illinois headed by Professor Hadis Morkoc first fabricated Low Temperature Gallium Arsenide (LT GaAs) semiconductor structures with significantly improved interface quality. Electronic devices incorporating these structures enabled the production of integrated circuits rivaling those made from silicon in their levels of complexity while offering the speed and power consumption advantages of compound semiconductors. These qualities, coupled with the superior radiation tolerance of LT GaAs circuits, are ideally suited to the production of Air Force electronic systems with advanced performance and reduced power requirements. LT GaAs can be produced at temperatures significantly lower than earlier forms of the material. In concert with DARPA, this new semiconductor was transitioned to industry very rapidly and found itself to be a critical component in MILSTAR satellites and the world's fastest photo detectors. It is also used in the B-2 bomber, F-15, F-16, F-18, and F-22 fighters, and the AMRAAM, Patriot, and TOW missiles.[56]

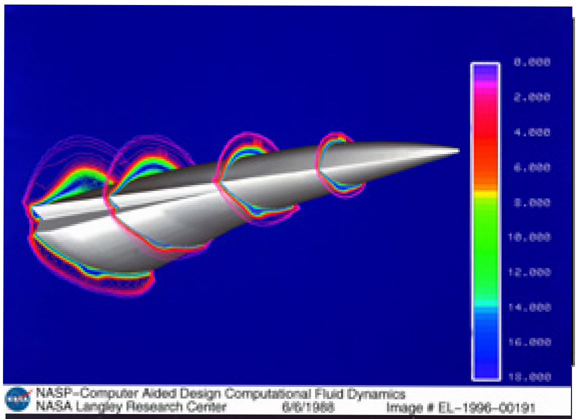
Swept Rotor Blade Design (1985-1988)



Swept wing design in supersonic aircraft reduces performance loss resulting from the shock wave interaction with the wing. This same concept was studied by AFOSR to make rotor blades in axial flow compressors more efficient, which led to increased performance. This new development improved compressor efficiency by almost 90 percent. Use of these blades resulted in aircraft engines with fewer stages and higher thrust-to-weight ratios. The requirement for fewer blades—from fewer stages—was also important in reducing requirements for replacement blades. Better thrust-to-weight ratios meant more powerful engine performance with an accompanying 20 percent increase in range due to reduced fuel consumption for longer loiter times. This technological breakthrough in engine component design solved a problem that aerodynamicists had struggled with for years. Aerodynamic experts long understood that shock waves hindered performance in supersonic aircraft, and that this was alleviated if the wings were designed to be swept relative to the direction of flight. As such, swept wing theory was applied to engine compressor blades with similar results. The Air Force spent $4 million, split between AFOSR and Air Force laboratories, on the basic and developmental research which ultimately was transitioned into actual use. Private industry invested millions more on the development of engines—both military and commercial—using swept blade technology, which is now commonplace in current engine design. This technological advance has saved millions in fuel costs.[57]

Medical Free Electron Laser (MFEL) (1985-present)

The MFEL had its genesis in AFOSR-funded basic research beginning in 1970. It was not until the early 1980s that a number of changes in the nature of medical laser research occurred. That decade witnessed increasing interest in the mechanisms of laser-tissue interactions, and new clinical applications based on these interactions came into use. One of the driving forces behind this change was the initiation of the Medical Free Electron Laser (MFEL) Program by the Department of Defense in 1985. Now known as the Military Photomedicine Program (MMP), this effort has a long history of accomplishment in studying and developing light-based medical knowledge and technology. MFEL pioneered the use of pulsed laser and other optical technologies in medical diagnostics and therapeutics, including a number of broadly applicable, "platform" technologies, with major civilian as well as military importance. It is estimated that several million medical procedures per month trace their origins to the MFEL program. Civilian applications have been spun-off to other funding sources such as the National Institutes of Health, various foundations, as well as private companies. In addition, numerous successful start-up companies have evolved from MFEL funded research and technology. Some of the important platform technologies devised under the program include: Optical Coherence Tomography (OCT), (See Page 71); broadly and routinely used in eye diagnostics; photochemical tissue bonding, which could ultimately replace sutures in many procedures; and photodynamic therapy for non-cancer applications has been a mainstay of the program. A major success of the program was in the treatment of wet age-related macular degeneration, now in clinical use; Bioluminescent imaging, invented and developed in various forms under the program, uses transfer of modified luciferase genes (which produce the protein that makes fireflies light-up), it has become a major technology for studying infection, wound healing and other cellular interactions; the plasma electron avalanche knife (PEAK) is a new broad-based surgical tool with important benefits in terms of precision cutting with bleeding control and minimal localized tissue damage. Two additional emerging platform technologies include miniature imaging endoscopes to provide images through a single fiber via a standard needle, and optical nerve stimulation, which has benefits over electrical in that single nerves can be stimulated and there are no direct contact effects. Dr. Howard Schlossberg, AFOSR Optical Sciences Program Manager, supported the Stanford FEL program beginning in 1972. Initially created and sponsored by AFOSR, the FEL program resulted in spin-off research and breakthroughs in other laser programs and related areas, with both military and civilian applications.[58]

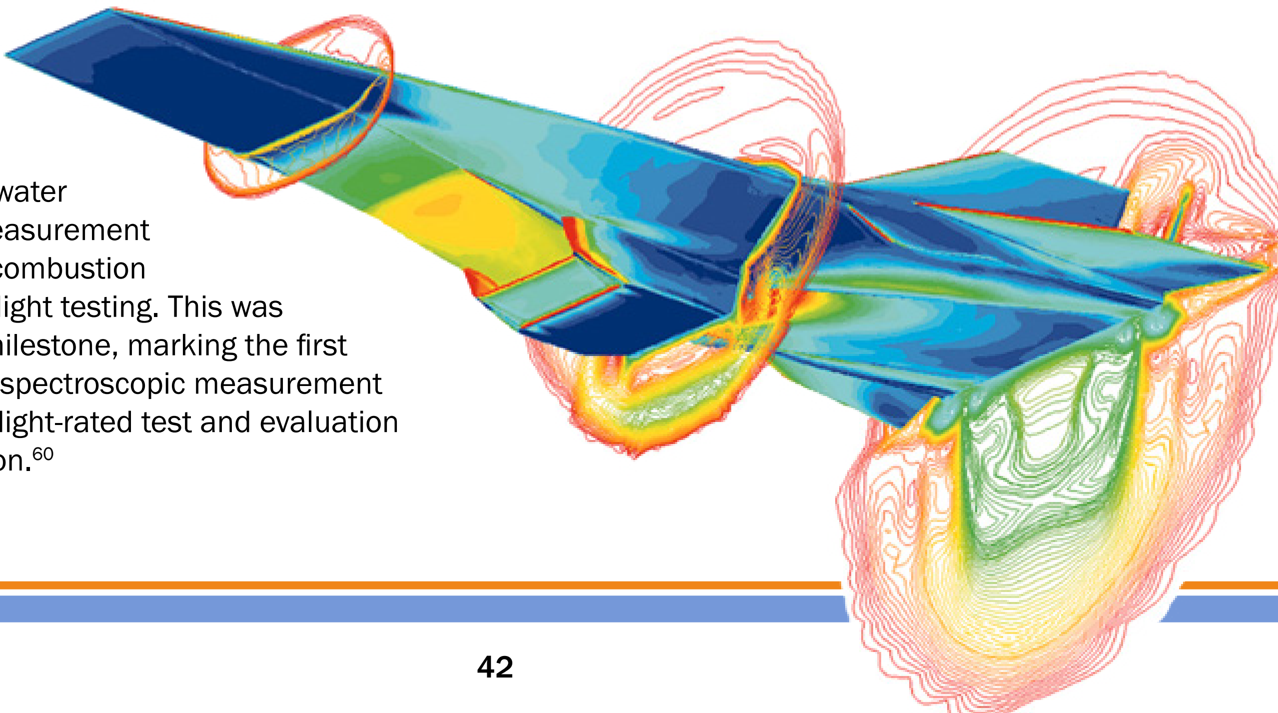


Shock-Induced Fuel/Air Mixing (1986)

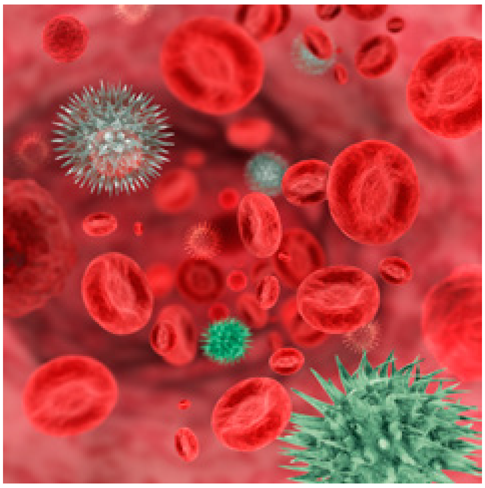
This AFOSR program, also known as Vortex-enhanced hypermixing, was based on research at the California Institute of Technology beginning in 1986 to boost the performance of hypersonic vehicle engines. In this concept, fuel and air mixing is enhanced through the interaction of orthogonal pressure gradient and mass density gradient components. This interaction creates a variable acceleration of the fluids associated with the injection of fuel into a high velocity air stream leading to a vorticity (rotation) in the flow, enhancing the mixing process. Shock structures are used to create large density and pressure gradients. This process was quickly adopted by NASA to boost performance of the National Aerospace Plane (NASP) scramjet engine.[59]

Early NASP Scramjet Design Benefits (1987-1989)

Professor Ron Hanson of Stanford University developed a new diagnostic tool which was adopted by the National Aerospace Plane (NASP) Joint Program Office (JPO) in 1989 for optimizing scramjet engine designs needed for hypersonic flight (AFOSR Grant # 89-0067). Air Force mission applications for this new technique included high-speed reconnaissance aircraft, manned interceptors and missile propulsion systems. The NASP office installed the new on-line spectroscopic measurement technique for oxygen and water vapor at the NASA Ames 0.4 meter (16 inch) shock tunnel used for scramjet performance tests. The measurement technique was based on the use of diode lasers with superior wavelength and modal properties. These properties made it possible to simultaneously measure multiple gas dynamic properties and chemical species in hypersonic flow test facilities through the attenuation of the laser beam by absorption and at points along the laser beam by laser-induced fluorescence. There were two significant benefits: (1) the laser's low cost, compactness and durability allowed the technique to be used in hostile testing environments such as aircraft combustors or jet engine nozzles, and (2) the absorption spectroscopy technique enabled combined measurements of propulsion parameters by providing simultaneous data on such parameters as the air mass flux entering the combustor and the combustion efficiency. The JPO used the water absorption measurement to determine combustion efficiency for flight testing. This was a significant milestone, marking the first application of spectroscopic measurement capability for flight-rated test and evaluation instrumentation.[60]



Discovery of Diazoluminomelanin (DALM) 1988-1992

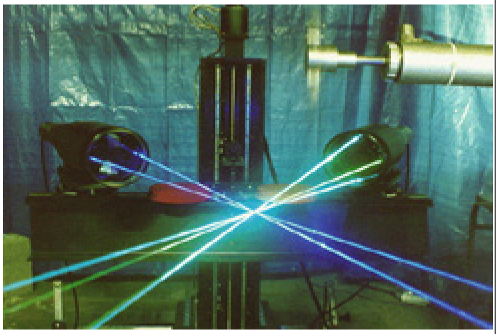


In 1988, Dr. Johnathan Kiel of the Radiation Sciences Division of the USAF School of Aerospace Medicine, was funded by AFOSR to purify and characterize DALM (biologically, chemically and physically), a substance with unique luminescent and free radical qualities. Separating the active DALM component from the many uninteresting and contaminating reaction products that were also generated proved to be no easy task. This program sought to employ DALM and its properties to neutralize biological warfare agents, specifically anthrax. Ultimately, other uses were realized, as DALM, being sensitive to microwave and other Radio Frequency radiation, has applications to RFR and microwave dosimetry, rapid identification of pathogenic microorganisms and the production of microwave-sensitive antibiotics.[61]

New Flow Control Techniques for C-17 Based on AFOSR Research (1988-1995)

In 1996 McDonnell Douglas Aerospace (MDA) conducted a technology development program on active flow control concepts for future improvements to the C-17's propulsion system. New technologies included active mixing enhancement for plume IR and jet noise reduction and pulsed fluidic thrust vectoring for enhanced maneuverability. These improvements enhanced C-17 affordability, survivability, and environmental compliance beyond current specifications and regulations. This innovative technology program, sponsored researchers at Georgia Tech led by Professor Ari Glezer, working in collaboration with Drs. Valdis Kibens, David Parekh and Mr. David Smith of McDonnell Douglas. The team learned how to actively control fundamental fluid dynamic instabilities in jet flows and to vector hot jet gases. These innovative active jet control techniques employ a set of piezoelectrically driven, pulsed fluidic, or synthetic jet actuators placed at the jet lip. These actuators dramatically alter the jet's flight dynamics by exciting fundamental instabilities that are amplified by the flow. Asymmetric excitation of the jet leads to more intense turbulent mixing on one side of the jet than on the other, which tilts or vectors the jet off axis. These active control techniques have been transitioned to the McDonnell Douglas C-17 Improvements & Derivatives Group which is performed the conceptual design and system integration studies. Professor Glezer's pioneering work is based solely on AFOSR support from 1988 through 1995.[62]

Phase-Doppler Anemometry (PDA) (1988)



This AFOSR/NASA funded program resulted in a system that can perform simultaneous non-intrusive measurements of the size and the velocity of individual spherical particles in liquids and gaseous flows. PDA is based on light-scattering interferometry and therefore requires no calibration, which in itself is a huge advantage. The measurements are performed at the intersection of two focused laser beams, which define the measurement volume. The innovation of this measurement technique is the determination of droplet size through a phase shift of the laser light caused by a change of index of refraction as the laser beam passes through a droplet. This approach virtually eliminated the errors associated with previous approaches that were based on size measurement through the detection of the amplitude of laser light scattered by droplets. Becoming commercially available in the 1990s, this instrument enjoyed considerable worldwide sales, and it became the standard testing instrument to characterize propellant injection in the combustion chambers of liquid fueled rockets. PDA has also found many dual use applications for a variety of technologies employing droplet and spray processes.[63]

The Pseudomorphic High Electron Mobility Transistor (1985-1991)

While most basic research discoveries take over a decade or more to transition to practical application, sometimes it can happen in much less time. The following is an excellent example of a relatively rapid and straightforward transition from basic research to industry and on to the warfighter. This AFOSR-sponsored research began with Professor Hadis Morkoc at the University of Illinois in 1985. His invention: the Pseudomorphic (meaning the materials do not quite match one another, but mutually adjust to accommodate the differences) High Electron Mobility Transistor, or P-HEMT. When Dr. Morkoc's new invention was transferred to a research team led by Dr. James Hwang (currently an AFOSR program officer) at General Electric's Electronics Laboratory in Syracuse, NY and fabricated under an IR&D program into submicron transistors with exceptional performance, Dr. Morkoc contacted Dr. Gerald Witt at AFOSR and suggested future research and development be conducted jointly with GE. While AFOSR does not usually give research grants to major corporations, to expedite the technology transfer, Dr. Witt made the exception to give the GE team a modest research contract. This funding was used by the GE team to leverage for more IR&D funding and ultimately resulted in record-breaking transistor performance in 1989. In 1991, the P-HEMT device was space-qualified for use in the MILSTAR communications satellite system. Thereafter, this technology was employed in almost every military or civilian high-frequency receivers that required low noise performance. For high-frequency power application such as in radar and communication transmitters, it was exceedingly more efficient than its predecessors. For two decades, the P-HEMT was used in almost every mobile phone handset to switch the wireless signals of different modes and frequencies. Finally, although the original P-HEMT was based on gallium-arsenide, the same pseudomorphic concept has been extended to indium-phosphide transistors, gallium-nitride transistors, and even silicon transistors with thin channels made of any of these compound semiconductors, which may allow complimentary metal-oxide semiconductor (CMOS) transistors to be scaled beyond the physical limit of silicon.[64]

Biological Corrosion in Electronic Packaging (1988-1992)

AFOSR-sponsored research discovered the first evidence that biological corrosion must be considered in the otherwise inert organic polymers used in electronic packaging. The research, carried out under the direction of Professor Ralph Mitchell at Harvard University, revealed that electronic-grade polyimides are susceptible to colonization by microorganisms. The microorganisms have the potential to cause corrosion either by directly metabolizing the polyimides or producing corrosive acidic chemicals by metabolizing chemical species adsorbed on the polyimides. Polyimides and other organic polymers, used in Air Force and commercial packaging for conformal coatings and resistive thin films in multilayer circuitry, were chosen because of their low dielectric constants and good resistance to environmental factors such as chemical corrosion, moisture and thermo-oxidated degradation. However, biological corrosion was not considered when polyimides were first selected. AFOSR-sponsored research, having identified this shortcoming, precipitated corrective measures to prevent what could have been significant failures in Air Force electronics systems.[65]

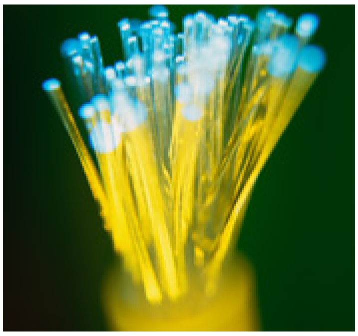
"When we at Caltech decided to make the transition from the pico-second to the femtosecond world of science, the vision of the Air Force, represented at that time by Drs. Larry Davis and Larry Burggraf, was instrumental in enabling us to build the first laser system at Caltech. I recall giving a lecture at a conference in Rochester, New York where the two Larrys came to me at the end of my lecture and were as excited with the new development as I was. Indeed, it was the support from AFOSR that made it possible for us to realize our dream. This tradition has continued, and in the post-Nobel era we were able to establish a new field of study; namely, four-dimension (4D) electron microscopy for the visualization of matter in space and time. Here again the AFOSR leadership, in this case, Dr. Michael Berman and his colleagues, saw the importance of the new development, and after submitting our proposal we were funded to carry out this research, which is now becoming versatile in the visualization of matter in different forms and shapes. My group and I are grateful for this continued support from the AFOSR. Happy 60th Anniversary!"

Professor Ahmed H. Zewail, California Institute of Technology

Support for the Pioneer Behind Femtochemistry (1989-present)

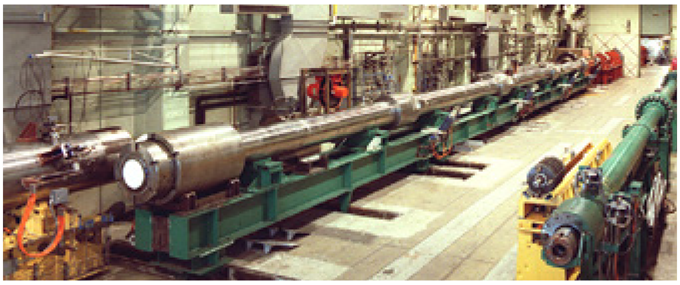
AFOSR first funded Dr. Ahmed Zewail, a chemist at the California Institute of Technology, in 1989 for a research program titled 'Ultrafast Chemical Dynamics of Reactions in Beams." AFOSR Program Managers continued to support Dr. Zewail in his effort to understand chemical reactions at their most fundamental level, as well as the speed at which these reactions occur. Zewail's work became the foundation for a new branch of study called "femtochemistry." By employing ultrafast laser techniques, Zewail could describe molecular level chemical reactions within very short time scales—in other words, to track the birth and death of a molecule within the timeframe of one millionth of a billionth of a second, literally capturing molecules and atoms in motion. For the Air Force, this process provides a greater understanding and control of the release of energy in chemical reactions in systems such as rocket propellants, chemical lasers and interactions of aerospace vehicles with their environments. Currently, Zewail is pioneering ultrafast time-resolved electron microscopy to probe materials and processes in time and space. In both femtochemistry and ultrafast electron microscopy, AFOSR has provided key support at the embryonic stages that has helped move these research areas from concept to reality. Zewail's work has had a profound effect on many scientific disciplines as well as numerous commercial and industrial production applications. Dr. Zewail received the 1999 Nobel Prize in Chemistry for his pioneering work in femtochemistry.[66]

A New Class of Lasers (1989-1995)



With AFOSR support, Dr. Dennis Deppe of the University of Texas at Austin, developed a new class of vertical cavity surface emitting lasers (VCSELs) which operated at one-tenth the power compared to contemporary conventional VCSELs. Small operating currents allow faster modulation and greatly increase the speed and efficiency of fiber optic data transmission. At the time, these new lasers provided the Air Force with more efficient, high-volume, long distance secure communication networks. By comparison, older VCSELs required relatively high operating currents because of the difficulty in fabricating small diameter current injection contacts. Deppe reduced the current injection contact diameter by selectively converting conducting aluminum arsenide at the contact's outer edge to insulate the aluminum oxide while maintaining a small conducting center. This process also reduced the active emitting volume of the laser, limiting the number of emitting modes and bringing the spontaneous emission characteristics under positive control. Dr. Deppe fabricated VCSELs containing buried layers of aluminum arsenide and exposed them to steam at 500° Celsius. The steam selectively converted the aluminum arsenide to aluminum oxide. Aluminum oxide is favored in laser applications because it is one of the few materials that can be buried beneath gallium arsenide and refracts light more sharply than gallium arsenide (gallium arsenide is an important material in the construction of surface emitting lasers). Dr. Deppe's process was critical to the formation of the buried layers that define the active cavity of a VCSEL.[67]

AFOSR-Supported Test Facility Saved Millions in Hypersonic Missile Testing (1989-present)

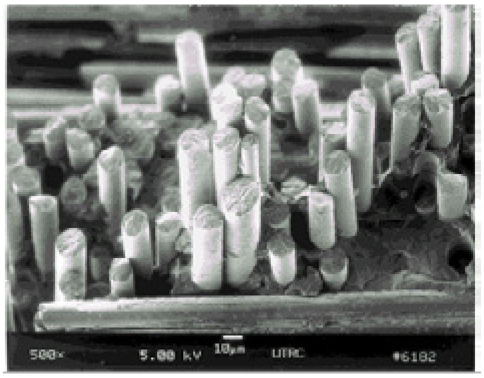


In 1983 the Calspan/University at Buffalo Research Center (CUBRC) was formed to perform fundamental hypersonic research. As the result of an assessment by CUBRC of the state-of-the-art in experimental research, an effort was initiated to design a new facility which would address problems associated with turbulent compressible flows, non-equilibrium air chemistry and combustion in the velocity range from 6000 to 14,000 ft/sec. In 1987 this design activity was supported by a grant from NASA, and the funds for construction of the driver section of the tunnel were received from AFOSR in 1989. The facility was completed in 1992 and operated as a government furnished facility in support of the Seeker Head Evaluation program. The Large Energy National Shock tunnel (LENS), was the first facility of its kind in the world capable of duplicating the flight environment that a hypersonic missile interceptor encounters. Before construction of the facility, the only way to obtain aero-optic bore sight error, jitter, and attenuation data on interceptor flights involved costly full-scale tests. While real world flight testing is still necessary, the new tunnel allowed the Air Force to save millions of dollars in designing future hypersonic missile systems by eliminating the need for upwards of 90 percent of actual flight test trials.[68]

New Nondestructive Evaluation Tool Identified Corrosion in Aging Aircraft (1989-1995)

In 1995, researchers at Iowa State University constructed a portable tool that detected corrosion in aging aircraft. With AFOSR funding, physicist James Rose and colleagues built the prototype instrument to find wall loss between the first and second layers in aircraft lap joints. The instrument, built at Iowa's Center for Nondestructive Evaluation, records the transient eddy-current response of an air-core coil next to the lap splice. Signals were digitized with 16-bit resolution at a sampling rate of 1 mega-sample and 1,000 repetitions per second. It was tested on simulated samples whose wall losses were machined, and on actual corroded lap splices supplied by Tinker AFB and Boeing. The instrument's measured response agreed with theoretical calculations based on a model developed under the same program. The instrument was evaluated in August 1995 at Tinker AFB during an Air Force-sponsored blind trial of new technology for detecting corrosion in aircraft panels. This technique, patented by the Iowa State University research team, was later licensed to a company that then marketed an instrument utilizing the technique.[69]

Interfacial Studies of Coated Fiber Reinforced Ceramic Matrix Composites (CMCs) (1988-1994)



In 1988, AFOSR funded researchers at United Technologies Research Center (UTRC) to develop a fundamental understanding of fiber coatings and interfaces related to Ceramic Matrix Composites (CMCs). AFOSR Program Manager sponsors included Lisolette Schioler, Larry Burgraff, Alexander Pechenik and Randy Sands. Dr. John Brennan at UTRC, in collaboration with university professors that included Professor Steven Nutt at Brown University, studied various fiber coating systems in high temperature CMCs and the effect of interfacial phenomena on high temperature mechanical properties that are critical to advanced gas turbine engine structures for Air Force aircraft. These studies were some of the earliest to apply atomic-scale, high resolution transmission electron microscopy (HR-TEM), parallel electron energy loss spectroscopy (PEELS), and Auger electron spectroscopy to CMCs. The outcome of this work led to a much more fundamental understanding of the chemistry and microstructure of the fiber/coating/matrix interfacial region and the influence of this region on fiber/matrix bonding and ultimately the strength and toughness of ceramic composite systems. While several fiber coating systems were evaluated, a Silicon Carbide/Boron Nitride compound was ultimately selected, and eventually became the state-of-the-art fiber coating system for CMCs. The research findings in the multiple AFOSR-funded basic research programs provided a good foundation for several follow-on Air Force-funded programs to develop 2400ºF-capable CMCs. Optimized glass ceramic matrix systems developed under these studies led to top barrier layer compositions for environmental barrier coatings (EBCs) later developed under multiple Department of Defense and Department of Energy programs to ensure long-term durability of CMC components in engine environments. In addition, these cooperative efforts resulted in several graduate students joining UTRC to continue working in this area as full-time researchers.[70]

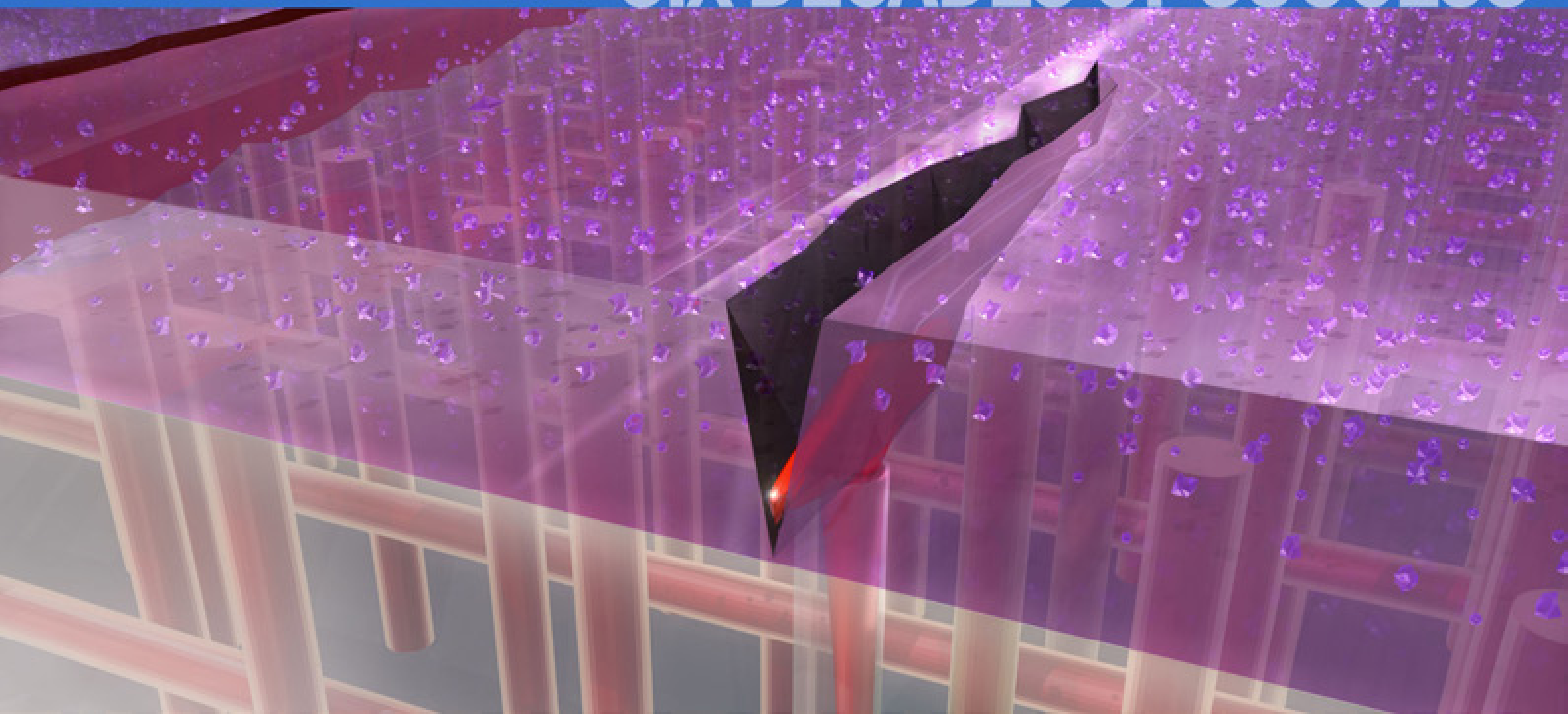
Excimer Laser Lithography (1980-1985)

In the early 1980's, pioneering research was done on the use of excimer lasers for lithographic patterning of microelectronic chips, by Kanti Jain of IBM and Daniel Ehrlich of M.I.T. Lincoln Laboratory, the latter funded by AFOSR Program Manager, Howard Schlossberg. In 1985 Ehrlich, with AFOSR funding, demonstrated projection writing of lines with an argon Fluoride (ArF) laser, with a resolution of 130 nanometers, in diamond-like carbon films. This breakthrough demonstration led to large programs by DARPA and others aimed at building an infrastructure for excimer laser projection lithography. As late as 1987, in a review article by Ehrlich, with Mordechai Rothschild, excimer laser lithography was described as speculative, with important problems yet unresolved. Subsequent advances have made ArF projection lithography the standard, by which all of the world's micro-chips are produced. The ArF laser is unique for this purpose as it emits considerable radiation at a very short wavelength (193 nanometers), necessary for the very small feature size of modern chips.[71]

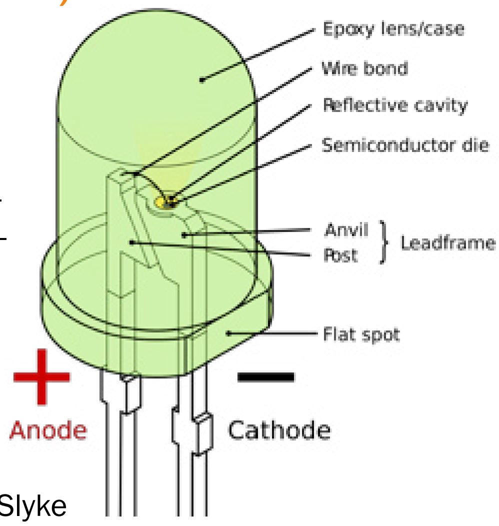
1990's

AFOSR BASIC RESEARCH

SIX DECADES OF SUCCESS



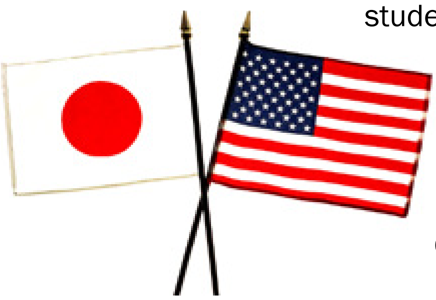
AFOSR Provided Critical Early Support for Flat Panel Organic Light Emitting Diode (OLED) Displays (1990-present)



AFOSR funding, through Program Manager Dr. Charles Lee, played a pivotal role in the field of flat panel displays, so much so that Dr. Stephen Forrest, an AFOSR-supported OLED primary investigator from the University of Michigan, stated, "...it is no exaggeration to claim that AFOSR support has given rise to the current global market in OLED displays." The current production volume of OLED displays (primarily used in mobile phones and, most recently, in 55" flat panel televisions) is approximately 10 million units per month, representing a $5B global business that is rapidly expanding. OLED technology though, experienced an evolutionary progression before it became practical. Prior to AFOSR involvement, the first major step leading to modern OLEDs was the demonstration of a bilayer fluorescent OLED by Chin W. Tang and Steven VanSlyke in 1987. Unfortunately, the maximum theoretical external efficiency of this device was only five percent. Funded in part by AFOSR beginning in 1990 and by DARPA from 1994 to 1999, this low efficiency problem was eliminated when Professor Forrest, along with his student Marc Baldo, and his collaborator, Professor Mark Thompson at the University of Southern California, introduced the concept of electrophosphorescence. This approach employed organic compounds containing a heavy metal atom that introduces spin-orbit coupling, resulting in an internal efficiency of 100%. With that advance, OLEDs immediately became the most efficient light emitters known, and the OLED industry began to grow to its current size. Electrophosphorescence is now used in almost every OLED display and lighting fixture that is commercially available. The primary partner to all large-scale manufacturers of OLEDs is Universal Display Corporation, a company co-founded by Professors Forrest and Thompson and others to commercialize this technology. Numerous other key technologies have been developed by Professor Forrest and are currently used by the OLED industry. Many of these technologies were developed with AFOSR support, including top emitting and transparent OLEDs used in all active matrix displays; stacked OLEDs—now a prime candidate for lighting; and phosphor sensitized fluorescence that allows fluorescent devices to exhibit 100% internal efficiency. Since 1990, AFOSR has provided critical support to generate a global industry that, in many ways, is just beginning.[72]

US-Japan Industry and Technology Management Training Program (JTMP) (1991-2000)

The JTMP began in 1991 at the University of Michigan with an AFOSR grant, the goal of which was to improve American competitiveness by understanding in detail the management and business practices used by Japan in the areas of science, engineering and manufacturing. During its ten year tenure, the JTMP carried out research, study, outreach and dissemination activities on Japanese technology management and manufacturing to industry and the military, and a variety of student programs. Major accomplishments include the publication of three books (especially the influential work, *The Toyota Way: 14 Management Principles from the World's Greatest Manufacturer,* by Jeffrey Liker); the growth and importance to American industry of the Lean Manufacturing process; and the growth of a significant student cadre well versed in lean manufacturing processes via Japanese industry internships. Due to this program, many facets of the Toyota Production System—especially what have come to be called in America "lean manufacturing methods," has been disseminated throughout U.S. industry, to include the Ford Production System, the Chrysler Operating System, and the Delphi Manufacturing System, to name but a few. Lean Manufacturing Conferences continue to meet on an annual basis.[73]



New Technique Enhanced Nondestructive Evaluation (NDE) of Aging Aircraft (1992-1995)

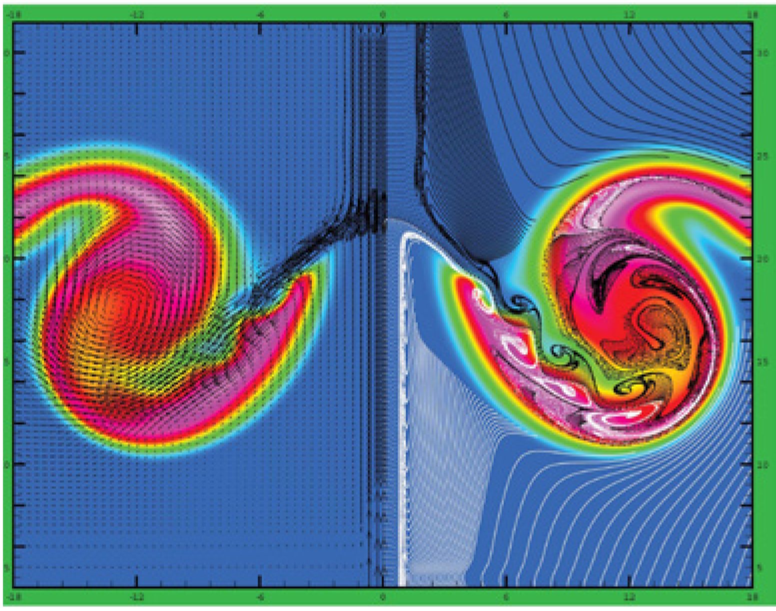
In the early 1990s AFOSR led an Air Force-wide program to develop new technology for inspection of its aging aircraft fleet. This was especially true regarding the aging KC-135 tanker and B-52 bomber fleets. Short of the labor intensive removal of panels from airframes, there existed no viable approach to identify aircraft in need of corrosion treatment. Research under this AFOSR NDE program at Vanderbilt University successfully demonstrated one technique that significantly improved the capability to detect cracks and corrosion in older aircraft. Funded by AFOSR Program Manager, Dr. Harold Weinstock, Professor John Wikswo led the Vanderbilt team which conducted the research in conjunction with an advisory group of engineers from Oklahoma City and Warner Robins Air Logistics Centers. The team used an array of small superconducting coils connected to an ultrasensitive Super-conducting QUantum Interference Device (SQUID) magnetometer to detect cracks in aluminum. At that time, a SQUID was the only form of magnetometer sensitive enough to make such measurements, and the team was able to image cracks under rivets in the second layer of aluminum in a mock-up of the fuselage conditions found in aging aircraft. Contemporary eddy current techniques in nondestructive inspection were not capable of this degree of resolution. Although this program did not result in NDE hardware, it did result in a unique and useable corrosion model, the funding for which was provided by the Warner Robins team, led by Dr. Richard Kinsey, who immediately saw the promise in Dr. Wikswo's approach. Dr. Deb Peeler, who led the AFRL corrosion research team in the late 1990s and early 2000s, not only developed the technical plan and roadmap that her team and the Aging Aircraft program followed during this period, she was also a key contributor to the design of the corrosion model itself, which was based on a simple material loss prediction model initially developed by Dr. Bill Abbott at Battelle. An article in the Summer 1999 Advanced Materials and Processes Technology newsletter, written by the commander of the Air Force Corrosion Control and Prevention Office, singled out the Vanderbilt study as being invaluable in enabling the Air Force to timeline model the deleterious effects of aircraft corrosion. The improved ability to detect hidden defects with this model continues today to help the Air Force fulfill the requirement to extend the service life of its existing fleet.[74]

State-of-the-Art Photodetector Developed through Collaborative Research Effort (1992-1995)

In 1995 researchers at the University of Michigan, in collaboration with other AFOSR-funded teams, including those at Lockheed-Marietta Laboratory and Purdue University, developed the fastest commercial photoconductor then available. The speed (seven picoseconds) and spectral range (400 to 900 nanometers) of the device made it ideally suited for a number of military and commercial applications including the characterization of devices for defense millimeter wave radar circuits and the improvement of Air Force optical communications systems. The photodetector was released for commercial use by the Picometrix

Company, a small business spin-off from AFOSR's Research Center of Excellence at the University of Michigan. The device was based on a new unique form of the semiconductor gallium arsenide (Low Temperature GaAs), developed at the MIT Lincoln Laboratory with AFOSR funding. Researchers at Lincoln Laboratory and the University of Michigan worked together in developing the optoelectronic applications of LT GaAs. This form of gallium arsenide is grown at very low temperatures, giving it such useful properties as high resistivity, good mobility, high dielectric breakdown strength, and very fast photocarrier recombination, particularly important for the photodetector released by Picometrix, which exists today as a leading supplier of high-speed optical receivers and terahertz instrumentation.[75]

Trapped Vortex Combustion Technology (1993-2002)

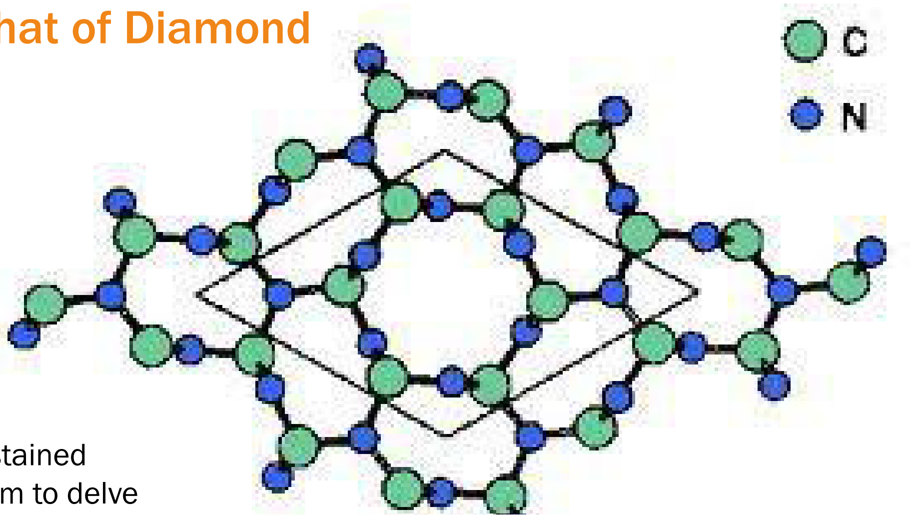


Trapped Vortex Combustion (TVC) is an innovative and potentially revolutionary concept that can significantly enhance gas turbine combustor performance while reducing exhaust emissions. The genesis for TVC occurred in 1993 when AFOSR Program Manager Dr. Julian Tishkoff funded a basic research program on flame-vortex interactions undertaken by Dr. William (Mel) Roquemore at the Aero Propulsion and Power Laboratory at Wright-Patterson AFB, OH (predecessor to the current AFRL Propulsion Directorate). Understanding these interactions is essential to developing advanced combustor concepts and developing modeling and simulation tools for combustor design in aerospace propulsion systems. This research revealed the stabilizing properties of vortices on flames and inspired the idea of the trapped vortex combustor, departing from the traditional swirl stabilized designs used in gas turbine engines for the past 60 years. TVC has two parts, a pilot combustor for stability and a main combustor for power; the pilot utilizes cavities to establish the recirculation zones needed for stable combustion, and each cavity is sized to provide a stable recirculation zone referred to as a "trapped vortex." By 2002, Dr. Roquemore's team, in partnership with General Electric (GE) Aircraft Engines, demonstrated significant improvements in turbine performance while drastically reducing emissions. In fact, the Strategic Environmental Research and Development Program, the environmental R&D arm of the Department of Defense, selected the TVC program as the Project of the Year for 2001 for the potential to lower pollutant emissions on a variety of fuels compared to conventional gas turbine combustors. TVC has demonstrated up to a 50% improvement in ignition, blow out, and altitude re-light over current-technology; significant emissions reduction; an operating range that is 40% wider than conventional combustors; and combustion efficiencies at or above 99%. These impressive performance and low emissions characteristics raise the possibility of numerous applications, by several organizations: (1) Air Force, Strategic Environmental Research and Develop Program and General Electric low emissions gas turbine combustor; (2) DOE, GE, and Ramgen for stationary power generation; (3) NASA for the Revolutionary Advanced Accelerator RTA X-43 program, and the Turbine Based Combined Cycle engine and low emissions gas turbine combustor; (4) U.S. Navy, ESTCP and GE for low NOx emissions combustor; (5) the Air Force for ultra-compact main burner, inter-turbine burner, and afterburner for small gas turbine engines; and (6) the Air Force for advanced engine concepts in the Integrated High Performance Turbine Engine Technology, Versatile Affordable Advanced Turbine Engines, and the Highly Efficient Embedded Turbine Engine programs. Papers from India, China, and France have also been published on TVC technology. The TVC concept, the result of an AFOSR-funded basic research program, represents the first completely new design approach for gas turbine combustors in more than 50 years, and is being investigated for numerous applications by the United States and several other countries.[76]

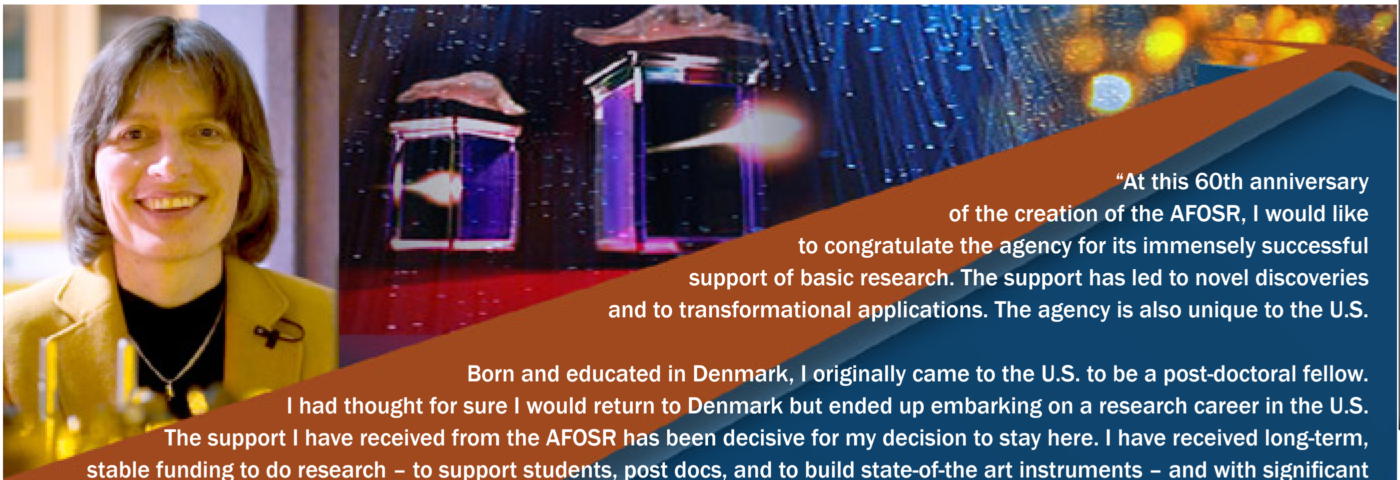
Quality and Reliability of Ceramic Ball Bearings (1994-1999)

In the early and mid-1990's, the main problem with the use of ceramic materials in bearing applications was their lack of reliability. With AFOSR support, researchers at the University of Florida identified specific types of flaws on the surface of silicon nitride ceramic ball bearings ranging from the innocuous to those that cause quick disintegration failure, but the causes of the various types of damage were unknown. A research team from the National Institute of Standards and Technology and Lehigh University then developed a fundamental understanding of fracture and fatigue in silicon nitride material, particularly on relationships between microstructure, surface damage, and failure. They demonstrated the detrimental effects of surface flaws and showed that microstructure can affect the evolution of contact fatigue. They also identified various types of previously unknown types of damage, such as powder processing flaws and reaction layers. Based on their data, they developed reliable methods and standards to detect near-surface flaws. Their work drastically reduced the population of surface flaws in newly manufactured bearings and significantly reduced the manufacturing costs. As such, the Air Force, DoD and NASA benefited from more powerful and efficient mechanical and propulsion systems based on a more reliable ceramic ball bearing. Air Force applications include auxillary power units, attitude control devices, and air breathing and rocket engines.[77]

Cubic Carbon Nitride: A Superhard Crystalline Material with Hardness Approaching that of Diamond (1995-1999)



Cubic Carbon Nitride (C3N4) was a theoretical prediction for many years prior to the late 1990s when an AFOSR-funded Northwestern University research team discovered the key. Despite numerous efforts by many research teams around the world, C3N4 remained elusive, but from 1995 through 1999, AFOSR sustained level funding to the Northwestern team to delve further into this uncharted scientific frontier. The conceptual breakthrough came when they realized the key to this technology was to "sandwich" layers of carbon nitride and titanium nitride which would stabilize carbon nitride in its cubic, rather than the thermodynamically stable hexagonal form. The hardness of this layered material approach measured at 45-55 gigapascal, making it the second hardest substance to diamond. The material was quickly transitioned to industry as a protective coating for disks and read-write heads as it provided significantly lower wear rates than traditional diamond-like carbon coatings. Sputter-deposited carbon nitride was eventually superseded by cathodic arc carbon for this purpose, but further research, funded by the National Science Foundation, led to improved carbon films with ultralow friction (coefficient of friction less than 0.01) even at high relative humidity, as well as a possible method that may achieve a revolutionary mechanism for a hard, as well as tough, coating process. If successful, it may represent a paradigm shift in the way we design coatings. These spinoffs would not have been possible without the initial long term/high risk AFOSR funding effort.[78]



"At this 60th anniversary of the creation of the AFOSR, I would like to congratulate the agency for its immensely successful support of basic research. The support has led to novel discoveries and to transformational applications. The agency is also unique to the U.S.

Born and educated in Denmark, I originally came to the U.S. to be a post-doctoral fellow. I had thought for sure I would return to Denmark but ended up embarking on a research career in the U.S. The support I have received from the AFOSR has been decisive for my decision to stay here. I have received long-term, stable funding to do research – to support students, post docs, and to build state-of-the art instruments – and with significant freedom to push into new areas of research. Over time, I have had many visits to my lab by AFOSR Program Managers and in each case, we have discussed my research and future plans in detail, and at a high technical level.

I have also received much encouragement from the agency and have felt strongly that we have worked as a team. As a result, I have felt a particular responsibility for producing the best research and novel results. Specifically, the funding from AFOSR led directly to the development in our lab of slow and stopped light and the observation that a light pulse can be converted into a perfect matter copy that can be stored – put on the shelf – sculpted, and then turned back to light. These results represent novel paradigms for powerful information processing, and patents based on the research have been issued.

I am very much looking forward to the continued collaboration with AFOSR and to keep learning about and help tackle the important problems facing the Air Force - in particular those hard problems that cannot be solved by engineering alone but whose solutions require the development of new science."

Professor Lene Hau, Harvard University

Stopping Light (1999-present)

An internationally celebrated physicist and AFOSR-funded researcher, who has been funded by several AFOSR Program Managers since 1999, has overseen work leading to the first successful demonstration of slow light. Dr. Lene Hau, professor of physics and applied physics at Harvard University, discovered applications through her work with light and matter that will impact the Air Force by providing significant advances in computing, optical networks, and quantum cryptography. In 1999, Hau slowed light down to 38 mph by shooting a laser beam through very cold atoms. Two years later, she halted light, restarted it and sent it on its way. In 2007, Hau and her research team stopped and extinguished a light pulse in a tiny, supercooled sodium cloud called a Bose Einstein Condensate (BEC), and then brought the light pulse back into existence in another atom cloud in a separate location. The information inside the light pulse was transferred from the first to the second cloud by converting the light pulse into a traveling matter wave, a small atom pulse that was a perfect matter copy of the extinguished light pulse. After the matter wave entered the second cloud, the atoms there worked together to restore the original light pulse. This experiment is a significant breakthrough for applications in coherent optical and quantum information processing. Currently, scientists and engineers working on optical networks and quantum cryptography are able only to store an optical signal, but Hau's work will enable them to have a greater degree of control over quantum information processing than ever before. Hau noted that this work provides the missing link in the control of optical information. While the matter copy is traveling between the two BECs, it can be trapped, potentially for minutes, and reshaped in whatever way required. The induced changes will then be present in the revived light pulse. Information encoded in light and transported in optical fibers can thus be converted to matter for rapid and powerful processing and subsequently converted back to light and sent down other optical fibers. Hau noted that the highlighted research is important also to chip integrated science and will result in new nanooptic devices and research into quantum physics at the nanoscale.[79]

"The AFOSR has been the single most important factor in my scientific career. Without their support the entire field of autonomous (self-healing) materials would probably not exist. AFOSR was the only agency to step forward and fund our work at a point when it was extremely high risk. Ultimately their investment yielded a successful launch of a wordwide research effort, several start-up companies, commercial products, and the realization of other material functionalities deriving from our original effort. I believe what defines AFOSR as a scientific organization is their willingness to support high risk – high reward efforts as part of the AFOSR research portfolio. My team has been extremely fortunate to work with some of the best Program Managers in the world over the years including Dr. Ozden Ochoa, Dr. Tom Hahn, and Dr. Les Lee. Each has supported our philosophy of pushing the boundaries of science and engineering, and their research horizon extends far beyond the current funding cycle.

I'm also extremely grateful that AFOSR and the Program Managers I've worked with see the incredible value of funding interdisciplinary work. Our team consists of an aerospace engineering (Scott White), a materials scientist (Nancy Sottos) and a chemist (Jeff Moore) all working side-by-side on a common research theme. Together, these disciplines allow us to tackle important and long standing problems while greatly increasing our likelihood of success. On behalf of our entire research team we wish the AFOSR a very happy 60th birthday and look forward to their next 60 years of exploration and discovery."

Dr. Scott White, University of Illinois at Urbana-Champaign

Self-Healing Materials: Can Air and Space Vehicles Live Forever? (1998-present)

In 1998 Dr. Ozden Ochoa, an AFOSR materials Program Manager, attended a workshop where Dr. Scott White from the University of Illinois at Urbana-Champaign presented a paper on "self-healing plastic." Ochoa, and follow-on AFOSR Program Managers, Dr. H. Thomas Hahn and Dr. Les Lee, enthusiastically followed up with Dr. White's proposal for a process whereby microscopic cracks in aircraft structures could heal themselves. Initially supported by seed money from the University of Illinois in the mid-1990s, and rejected by other funding agencies because they thought his work was "too high risk," AFOSR funding resulted in a seminal 2001 paper in the journal Nature: "Autonomic Healing of Polymer Composites," which gained worldwide attention. Dr. White's initial concept consisted of placing microcapsules of a healing agent and a special catalyst into a structural composite-matrix material. When damage occurs, the microcapsules rupture and release the healing agent and catalyst into the damaged area filling and bonding the void. Further research has discovered a simpler and economical catalyst-free system, and demonstrated a technique for fabricating 3-D microvascular networks within various materials which can continuously transport the healing agent to damaged sites via a circulatory like system. White noted that these miniscule networks could work as compact fluidic factories in sensors, chemical reactors and computers, and could also cool in response to a heat load, or, conversely, heat when too cold. They can also be configured to be self-diagnosing, and be able to sense biological agents. Self-healing micro-electronic structures are also being investigated to obviate dielectric breakdowns because of thermal or mechanical cycling. With new catalysts and healing agents, material integrity can be assured up to approximately 180 degree C. This basic research program has progressed from a capsule-based, to a vascular system, to an intrinsic approach to self-healing, wherein with the use of dynamic polymers and inert scaffolds, one can synthesize two types of dynamic covalent bond based polymer systems, which can be forever changed from liquid to solid and vice versa when renewed bonding is necessary. What began in 1998 as a high risk technology endeavor has resulted in the possibility of a highly sophisticated approach to the autonomous healing of aircraft structures. This program is an unparalleled testament to the high-risk high-payoff philosophy of AFOSR Program Managers in support of the Air Force mission.[80]

Space Vehicle Communication: High Temperature Flowing Afterglow (HTFA) (1996-present)

High temperature plasmas associated with both the ionosphere and space-vehicle reentry greatly affect radio frequency signals and hypersonic propulsion systems are enhanced by plasma igniters. All these environments impact mission effectiveness. As such, AFOSR Program Manager Dr. Mike Berman funded a team at AFRL's Space Vehicles Directorate, led by Dr. Albert Viggiano, which successfully made direct measurements of plasma chemical reactions over the entire temperature range needed by Air Force radio propagation and combustion models. The High Temperature Flowing Afterglow measurement technique quantifies the precise impact of the plasma's ion-molecule reactions. This results in far more accurate ionospheric modeling data. Previous laboratory measurements were only able to study reaction rates at temperatures up to 900 Kelvin, well below the actual plasma temperatures of many AF systems. The HTFA measures plasma processes at temperatures up to 1800 Kelvin, and allows the study of ion-molecule reactions and electron-molecule reactions at or near the temperatures seen in Air Force operations, and thus allows for better prediction of the communications effects of plasmas on vehicle reentry and ionospheric radio wave loss, as well as plasma assisted combustion. The chemistry is also applied in the High Altitude Auroral Research Program (HAARP), as well as plasma etching research. The HFTA program continues to this day to expand and improve, including the demonstration of the highest true temperatures for which ion and electron molecule reactions have been studied. Overall, this program has significantly advanced the nation's space communications capability and our understanding of re-entry environments.[81]

Supersonic Micro-Jets for Joint Direct Attack Munition (JDAM) Flow Control (1999-2007)

In late 1999, AFOSR-funded work to explore the use of supersonic micro-jets for flow control in applications associated with Short Takeoff and Vertical Landing (STOVL) to minimize disruption at takeoff and landing. This program was begun by AFOSR Program Manager Dr. Steven Walker, who awarded a research grant to Dr. Anjaneyulu Krothapalli, a professor of mechanical engineering at Florida A&M University and Florida State University. Funded with a combination of Historically Black Colleges and Universities/ Minority Institutions funds and an AFOSR basic research grant, the FAMU/FSU team, led by primary investigator, Dr. Farrukh Alvi, developed a successful supersonic micro-jet based active-adaptive flow control system that led to its application in a project called High Frequency Excitation Active Flow Control for Supersonic Weapon Release, or HIFEX, to help achieve safe weapon dispense at supersonic flight speeds. The ultimate application of this technology was greatly assisted along the way by Dr. Anuradha Annaswamy at MIT with regard to control theory. The successful FAMU/FSU flow control program was ideal for application to the HIFEX program. By placing micro-jets upstream from a weapons test bay containing a Mk-82 Joint Direct Attack Munition (JDAM), researchers were able to stabilize the initial munition release. In August 2007, researchers accomplished the first successful full-scale test release of any air delivered munition at Mach 2, or two times the speed of sound.[82]

1990's

Boeing Used AFOSR-funded Technology To Design Flight Controls for SLAM-ER, JDAM, and MMT

Projective Control Theory Used To Project Optimal Autopilot Into Output Feedback Autopilot

Reusable Flight Software

Decades of AFOSR-funded basic research supported the development and evolution of LOCASS and JDAM

JDAM:
Adaptive Neural Net Control (Theory): mid-1990's
Optimal Trajectory Shaping Guidance Laws (Theory, Algorithms): 1980's
Computational Fluid Dynamics (Algorithms): 1980's

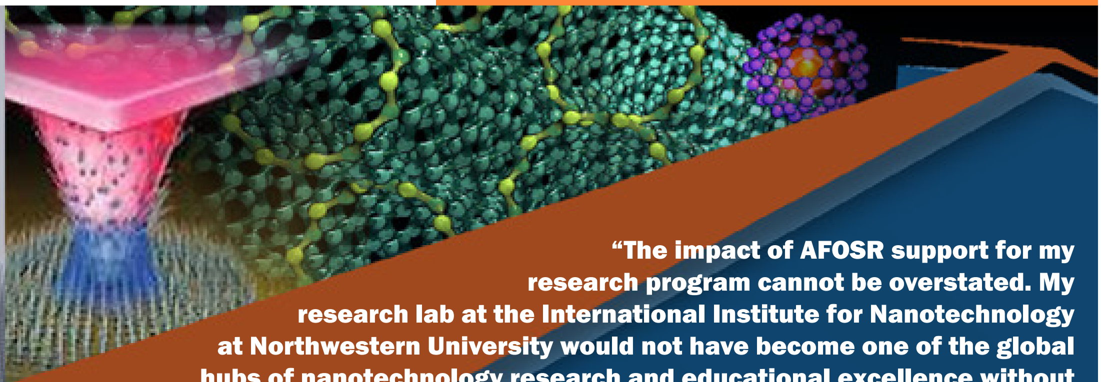
JDAM and LOCASS
Hydrogen and alkali maser research: 1950's
Control theory research leading to the Kalman filter: 1950's
Maser, Laser, and Solid State Lasers: 1950s-1980's
Monolithic microwave integrated circuits: 1980's
Compound semicounductors research: 1980's
Modern Control Theory (Theory, Algorithms): 1980's
Advanced semiconductor devices: 1990's
Precise measurement of atomic transitions used in atomic clocks: 1990's

LOCASS:
Multi-mode Warhead (Phenomenology, Theory): 1980's
Cooperative Attack (Theory, Concepts): 1999-present
Agile Autonomous Control (Theory, Concepts): 2000-present

AFOSR & Smart Weapons (1950's - 1990's)

AFOSR program results transitioned into development of:

- Standoff Land Attack Missile-Expanded Response (SLAM-ER)
- Miniaturized Munitions Technology (MMT)
- Joint Direct Attack Munition (JDAM)
- Low Cost Autonomous Attack System (LOCASS)



"The impact of AFOSR support for my research program cannot be overstated. My research lab at the International Institute for Nanotechnology at Northwestern University would not have become one of the global hubs of nanotechnology research and educational excellence without their support. The AFOSR understands the importance of funding cutting-edge scientific research as an avenue to high impact scientific discovery and appreciates that high-risk research often leads to high-reward payouts for both the civilian and military communities over the long term. I have built strong relationships with the AFOSR PMs who have funded my work over the past 15 years. The PMs have been integral members of my team, who I look to for scientific feedback and advice, and I am proud of the programs we have collectively built. I hope that my relationship with the AFOSR continues to flourish over the rest of my academic career.

Happy 60th Anniversary to the AFOSR!"

Professor Chad Mirkin, Northwestern University

Dip-Pen Nanolithography: Manipulating Molecules and Much More (1997-present)

In March 2012, National Geographic published a special issue titled "100 Scientific Discoveries That Changed the World." At the number one position was a research program that began in 1997 when AFOSR-funded a Northwestern University researcher by the name of Chad Mirkin. AFOSR took a chance on a process called Dip-Pen Nanolithography (DPN), and what Dr. Mirkin himself noted, was "a far out idea" but proved to be basic research that changed the world. First highlighted in the journal *Science* in January 1999, DPN is a technology that builds nanoscale structures and patterns by drawing molecules and materials directly onto a substrate. This process was achieved by employing an Atomic Force Microscope (AFM), the tip of which has the innate capability to precisely place items and draw complex patterns made of molecules and materials at the nanoscale level. The AFM is basically an extremely small stylus that can be used to determine surface topography. Mirkin's fundamental contribution was recognizing that it could be used as a "pen" to print structures on a surface through materials transfer, rather than through an energy delivery process—the latter being the approach taken by all previous researchers. While the National Geographic highlight gives due credit to the significant impact of nanolithography and Mirkin's role in developing Dip-Pen Nanolithography (DPN), what warrants further notice are the many-faceted and overarching consequences of his subsequent revolutionary discoveries. DPN has led to the development of powerful new point-of-use nanofabrication tools, ways of miniaturizing gene chips and pharmaceutical screening devices, methods for making and repairing photomasks used in the microelectronics industry, and high-throughput methods for discovering structures important in biology, medicine, and catalysis. Dr. Hugh DeLong, the AFOSR Program Manager who funded Dr. Mirkin in 1997, states: "Dip-Pen Nanolithography revolutionized the way one can assemble nano-architectures on a surface, thus opening the door to constructing a wide range of individual structures, assemblies, and cellular arrays that utilize multiple length scales at once. Mirkin developed the equivalent of a desktop nanofab and in the process did for nanofabrication what the desktop printer did for information transfer." Dr. Mirkin solved the challenge of making, manipulating, and controlling things interesting to biologists, material scientists, and chemists on a small scale. His efforts resulted in mass production techniques that allow enormous amounts of information to be carried or placed in an exceedingly small space, and in doing so, revolutionized aspects of biology, medicine, and electronics. A relatively small basic research investment by AFOSR has led to a worldwide industry and field that now employs thousands.[84]

New Synthetic Polymer Contributed to Development of Flat-Panel Color Displays (1990-1993)

In 1993, Professor Frank Karasz of the University of Massachusetts at Amherst successfully synthesized a new polymer that allowed "high definition" information to be seen on flat-panel displays. This type of display has an advantage over conventional cathode ray tube technology due to its light weight and reduced volume, important features in environments such as aircraft cockpits. Unlike liquid crystalline displays, flat-panels offer a wide angle of view. His discovery represented an important milestone in the effort to develop flat-panel color displays for military and commercial applications in command, control, communications and intelligence (C3I). Professor Karasz' accomplishment involved the successful synthesis of an electroluminescent polymer, poly [p-phenylene vinylene] block copolymer, that enabled fabrication of a blue-light emitting diode (LED) structure. This was possibly the first reported blue emitter in a polymer LED (PLED) that used a solution processible macromolecule. The blue emitter, together with the red and green type, enabled the presentation of full color information in a closed-in environment. Scientists consider electroluminescent polymers a better material than inorganic semiconductors and organic crystals for use in flat-panel displays because of their potential for quantum efficiency in all wavelengths, long-term stability and low fabrication costs for large-scale devices. Since a Cambridge University group first reported an electroluminescent polymer that emitted green-yellow light, many research groups around the world have been attempting to generate a blue-light emitting polymer. Most of these efforts focused on changing the chemical structures of the polymers to yield larger "band gap" electronic structures, but the Karasz group elected to increase the band gap by controlling the conjugation length of the PPV units. Their highly technical, innovative approach to solving the problem brought a polymer based, low-cost flat-panel color display a step closer to reality, and their PLED approach could potentially lower the cost of flat panel manufacture because it could be processed with a polymer approach with printing, painting and casting.[85]

Joint Precision Air-Drop System (JPADS) (1999-2006)

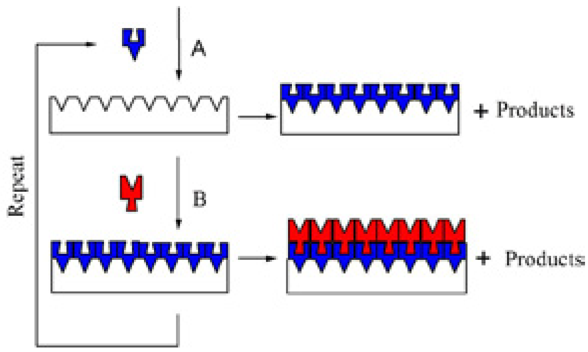
It was in 1998 that severe shortcomings regarding humanitarian airdrop operations in Bosnia, under Operation Joint Endeavor, prompted the Air Force to address the significant challenges in making safe and effective cargo airdrops from 15,000 feet and above in constrained airspace. Dr. Steve Walker was the AFOSR Program Manager who oversaw the basic research investment in what would become the Joint Precision Airdrop System. Walker funded the U.S. Army Research Development and Engineering Command (RDECOM) at the Natick Soldier Center in Natick, Massachusetts, to explore various solutions. This was an unusual program for AFOSR, since it was between basic research and development work with universities, companies and government labs. Steve Walker's counterpoint at Natick was Richard Benney. AFOSR's contribution to this revolutionary program was the investment in three key areas—winds prediction, guided and controllable air drops, and the computational algorithms and planning software required to tie it all together--the "mission planner" segment of the program. Draper Labs in Cambridge Massachusetts was responsible for the mission planning software, and Planning Systems Incorporated was responsible for the weather part of the package. By 2002, AFOSR's investment was paying off with strong test results: the Natick-based research team demonstrated the system as affordable and reliable—markedly increasing the accuracy of high altitude airdrops. In August 2006 the 774th Expeditionary Airlift Squadron employed JPADS to drop supplies to a U.S. Army unit serving in Afghanistan, marking the first time the system was used in a combat zone by the U.S. Air Force. JPADS saves lives by reducing the need for high risk supply convoys and avoidance of Improvised Explosive Devices (IEDs). The system also takes Air Force cargo aircraft and aircrews out of harms' way by flying above and offset from most ground threats. JPADS provides a just in time re-supply capability to remote locations not accessible by convoys or even helicopter. It significantly increases the survivability of critical supplies and enhances humanitarian relief operations.[86]

Small(er) Satellite Programs (1997-present)

Aimed at supporting an Air Force Space Command requirement issued in April 1997, AFOSR-funded a potentially revolutionary space program, Technology Satellite of the 21st Century (TechSat21). This program was driven by the fact that conventional satellites can weigh several tons, require long lead-times to build, and cost $25,000 to $50,000 per pound to launch. The TechSat21 objective was to create satellites about one-tenth the size of conventional satellites (about 250 pounds) but could provide data as good, or better than their bigger cousins, by flying in multiple satellite clusters and communicating in concert with each other. AFOSR's contribution to this flagship program were the basic research contributions to address crucial questions in the areas of Synthetic Aperture Radar, collective behavior, micro-propulsion, and ionospheric science. AFOSR-funded multiple successful programs in these various areas at universities, industry, and within several AFRL Technical Directorates. One notable initiative, begun in 1999, is the University Nanosatellite Program (UNP) jointly funded by AFOSR, the Air Force Research Laboratory's Space Vehicles Directorate, the American Institute of Aeronautics and Astronautics and the Space Development and test Wing of Space Command. Participating universities form partnerships with other universities and private industry to demonstrate a host of NanoSat capabilities: the collection of space weather data, serving as radar calibration targets, testbeds for guidance and navigation controllers, and the measurement of atmospheric drag. The program highlights these miniature bus technologies, as well as formation flying and distributed satellite capabilities, that may enable more agile, less expensive and smaller satellites. In addition, over 4500 students from 27 academic institutions have benefited from this unique program. AFOSR also partially funds the United States Air Force Academy's small satellite engineering program called FalconSat, wherein satellites are designed, built, tested and operated by USAFA cadets.[87]

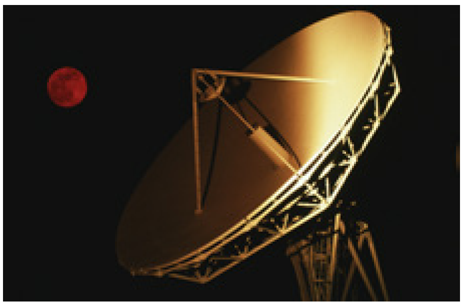
Atomic Layer Deposition: Painting at the Atomic Level (1999-present)

Funded by the AFOSR since 1999, Dr. Steven George, at the University of Colorado, Boulder, has been responsible for several unique breakthroughs in the field of Atomic Layer Deposition, or ALD. It allows one to control the physical and chemical properties of materials one atomic layer at a time. ALD did not originate with Dr. George. This process was actually preceded by Atomic Layer Epitaxy (ALE) beginning in the 1970s with applications in use through the 1990s. But while ALE could do some things well, it had severe limitations as to what materials one could bind to a surface. ALD can deposit a wide range of materials from organic to inorganic to specific metals, or even a hybrid



composition of organic with inorganic. With the ability to combine such things at the atomic level in sequential alternating layers that have never been in combination before, you may end up with a chemistry that yields unique new properties. This possibility was the driver behind AFOSR's support for Dr. George's program. When Dr. George first described the ALD process to AFOSR Program Manager Dr. Michael Berman in 1999, Berman was struck by how this process seemed to offer a method that would give unprecedented and revolutionary control over the size, composition, and properties of nanoscale materials. The resultant ultra-thin coatings have a wide range of uses, from inexpensive, thin, transparent non-metallic high tech potato chip bags that ensure freshness, to the creation of new types of flexible waterproof solar cells. There is one area where ALD can do something not otherwise possible--coatings for Micro-Electro-Mechanical Systems (MEMS), where there is literally no other technique that can coat small MEMS widgets--micron size or smaller--where they are not only exquisitely small, but you do not have line-of-sight to reliably reach and coat all surface areas. For MEMS coating requirements, the ALD application process is revolutionary. Dr. George's group also found that protective ALD films, when deposited on the surface of battery electrodes, with a thickness of only four to five angstroms, can significantly help stabilize a battery's capacity to maintain its charge. After a couple hundred cycles the battery may degrade to fifty percent of capacity without the ALD coating; with the ALD coating, the battery degrades five to ten percent. This significantly enhances lithium ion battery performance--good news for warfighters weighed down by numerous battery packs and for future electric vehicles. The ALD process can be applied to an extremely wide range of systems including coatings on aircraft canopies, protective coatings on particles and nano-particles, creating insulators in integrated circuits, and controlling catalysts and sensors. What remains to be seen are the even more unique coatings on an increasingly wider range of materials, hence enabling new potential applications.[88]

High Temperature Ion Chemistry Program Improves Geolocation and Space Radio Communications (1995-present)



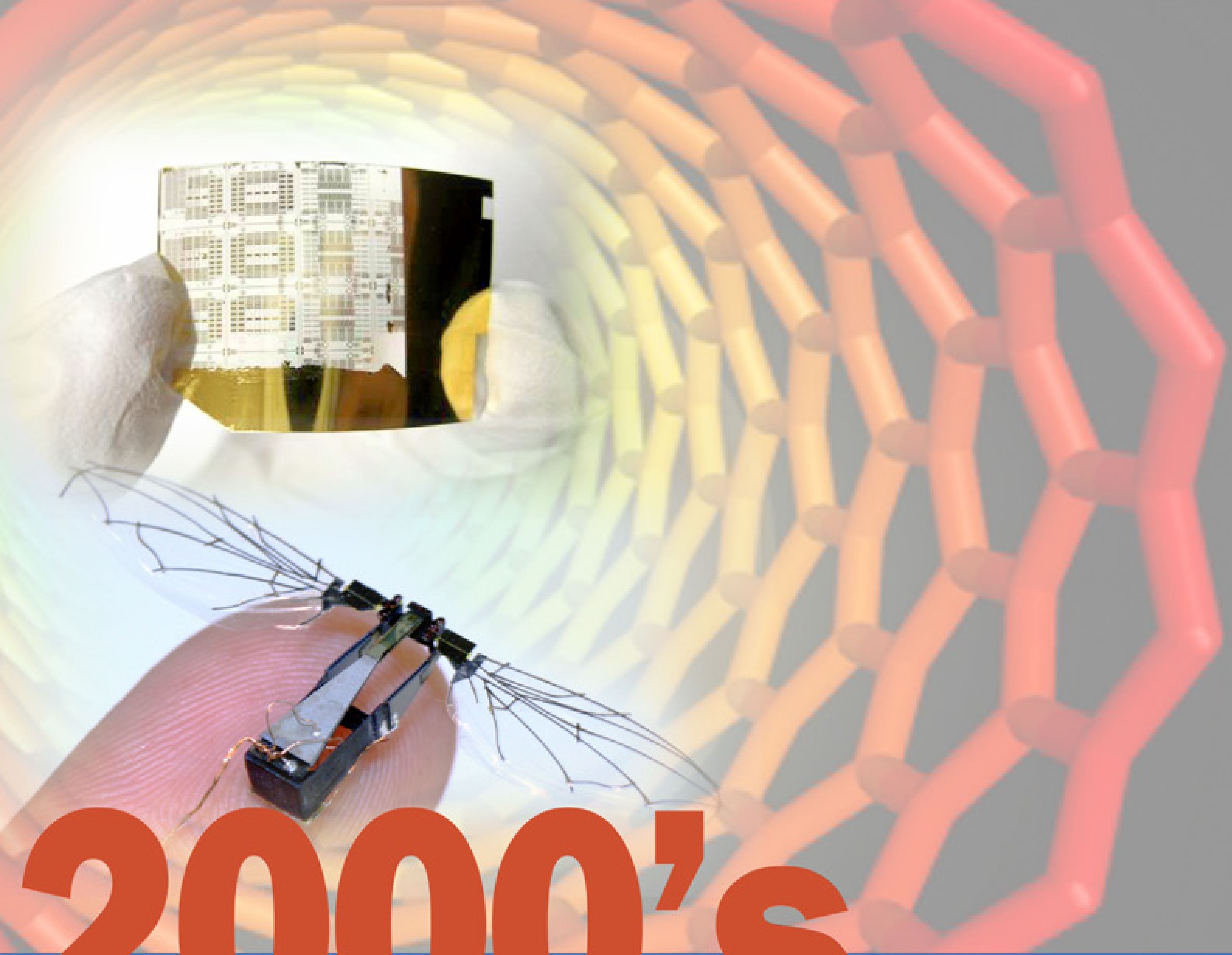
In 1995, an AFOSR-supported research team at the Phillips Laboratory's Geophysics Directorate demonstrated the world's first apparatus to study ion-molecule reactions at temperatures up to 1800 K, twice as high as any previous lab device measurement limit. Drs. Albert A. Viggiano and Robert A. Morris developed the High Temperature Flowing Afterglow (HFTA) device in which detailed measurements can be made of the reactions of ions at high temperatures that can affect radiowave propagation. Ions generated by aerospace vehicles such as jets, rockets, and hypersonic vehicles, can reach temperatures of several thousand degrees. These ions can affect radiowave propagation, making communications difficult or even impossible. Since its introduction in 1995, the application of this technology has been used to improve the Air Force's ability to accurately pinpoint the location of missiles, rockets, and hypersonic vehicles in space and to maintain constant communication with these assets. It is also employed to improve models used to calculate radar cross sections. Dr. Viggiano and Dr. Morris also found that the lower temperature limit of previous instruments provided unreliable data for modeling high-temperature plasmas. Using the HFTA device, they studied the reaction of oxygen positive-ions with molecular nitrogen, the main reaction that controls the electron density in the earth's ionosphere. Results from their experiments showed that extrapolations based on low temperature data were in error by at least a factor of two at 1600 K. The device has also been used to study ionospheric chemistry for better prediction of sub-auroral polarization streams, as well as chemistry related to reentry plasmas and plasma assisted combustion.[89]

"I am extremely grateful to the AFOSR for launching my career at the University of California, and for having the courage to fund ambitious, high-risk research. They constantly encouraged scientific excellence, enthusiastically shared a common vision, and deeply appreciated the challenges of integrating physics and electrical engineering to explore new phenomena in the solid state. The Program Managers at the AFOSR were leaders in funding interdisciplinary research and deeply understood the strong relationship between materials synthesis and scientific discovery. Without their steadfast support and thoughtful guidance, the field of quantum spintronics would almost certainly not be where it is today. Perhaps most important, the excitement of this rapidly expanding area continues to attract some of the brightest students in the country, making the AFOSR responsible for developing the successful careers of literally dozens of researchers throughout industry and academia. On behalf of all of my students – past, present, and future – we wish the AFOSR a very happy 60th anniversary!"

Professor David D. Awschalom, University of California Santa Barbara

Quantum Information Processing/Spintronics (1992-present)

It was during a 1991 research conference in Berlin, Germany, that AFOSR Program Manager, Dr. Harold Weinstock, met Dr. David Awschalom, who had just accepted a professorship at the University of California at Santa Barbara. Dr. Weinstock subsequently provided Dr. Awschalom's first research grant upon his taking residence at UCSB, and AFOSR continues its support of Dr. Awschalom to this day—and with good reason. Since 1992 David Awschalom pioneered the field of semiconductor spintronics, including fundamental discoveries of coherent spin generation, transport and detection in the solid state, and the development of new experimental techniques and materials engineering for spin-based quantum information science. His experiments explore and manipulate the electron spin in a variety of nanometer-scale systems, and led to surprising discoveries including long-lived spin coherence and the spin Hall effect. The work has generated new probes of fundamental spin interactions for the scientific community and opened the possibility of future quantum technologies. Dr. Weinstock funded Professor Awschalom's fundamental research in Coherent Manipulation of Spins in Semiconductors, as well as Manipulation and Control of Nanometer-scale Magnetism for Multifunctional Information Processing. These two fields, in particular, have the potential to improve future Air Force systems through the utilization of quantum information processing. Dr. Weinstock states that "Professor Awschalom's current research on the manipulation and control of individual electronic spin states in diamond films is leading the way to room-temperature-based quantum computing, opening a new generation of information science that will dwarf today's state-of-the-art computing technologies." The Air Force could realize dramatic benefits from this effort in ultra-secure communications, subatomic storage, phenomenally fast computing power, and new code-cracking capabilities.[90]



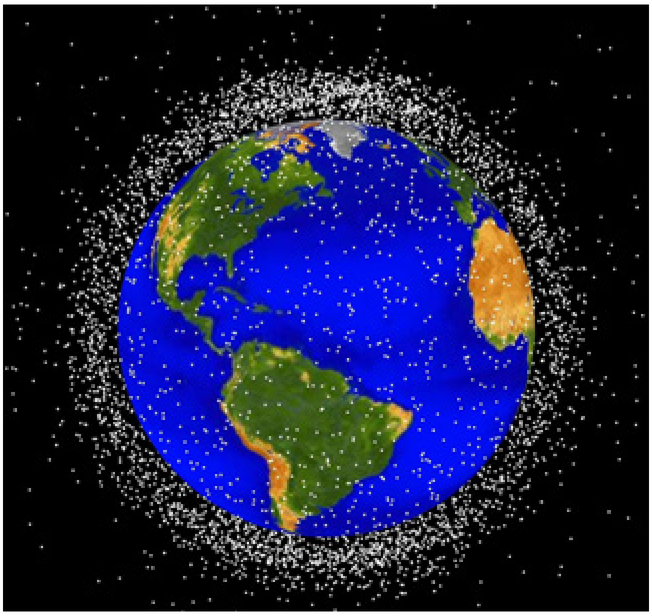
2000's

AFOSR BASIC RESEARCH

SIX DECADES OF SUCCESS

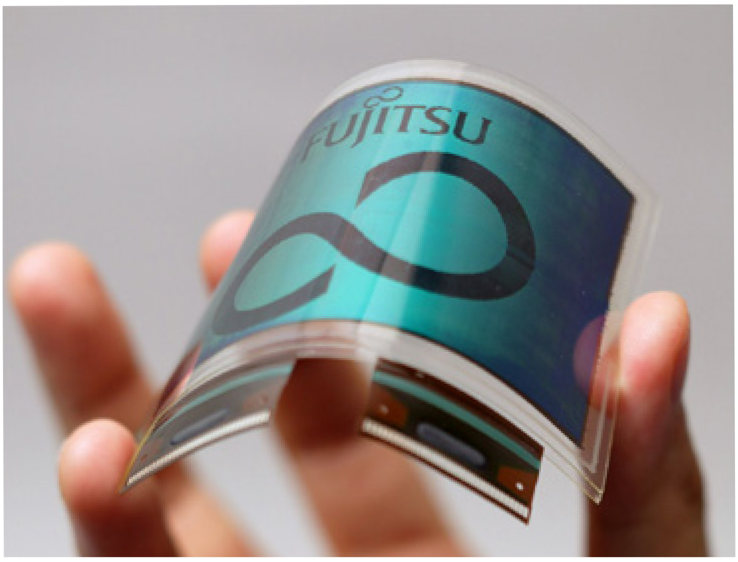
2000's

Advanced Concepts In Space Situational Awareness (SSA) (2000-present)



AFOSR-funded researchers invented the Physically Constrained Iterative De-convolution (PCID) algorithm and proved that this algorithm achieves or closely approaches the theoretical limits of image quality. The initial development of PCID was funded by AFOSR in FY2000 as an Air Force Research Laboratory Directed Energy (AFRL/DE) lab task. PCID is an iterative image restoration algorithm. It estimates and removes atmospheric and system blurring from one or more frames of blurred imaged data to produce a single high-resolution picture. PCID is being further improved to incorporate additional data such as wavefront sensor measurements in order to generate even higher-quality image restorations. Armed with this essential fundamental knowledge of PCID capability, the DoD determined sufficient computational power existed to warrant investment in a large software development effort to produce an engineering tool which would be fast enough to provide timely operational SSA to the warfighting commands. Thus, the Institute for Space Situational Awareness (ISSA) was founded and funded to take advantage of this basic research accomplishment which is in current SSA application as well as other uses.[91]

Bendable Electronics (2008-present)



AFOSR has provided research funding for fast, bendable electronics on two fronts: organic/polymeric materials and inorganic/semiconductor applications. Dr. Charles Lee, the AFOSR Program Manager who supports the organic/polymer effort, notes that because organic materials are flexible and can be printed onto large areas, they have potential uses in conformal electronics over large structural areas or antennas. Drs. Tobin Marks of Northwestern University and Zhenan Bao of Stanford University, working independently, have been making great progress regarding the charge transport speed, as well as creating air-stable negative charge conducting organics as well as positive charge conducting materials, a necessary combination to create sophisticated electronic circuits. Dr. Marks, in collaboration with a small company, have been able to demonstrate standard silicon (CMOS) type circuitry based on organic materials. The organic/polymeric electronic materials research effort is now investigating materials that can be applicable to "stretchable" electronics. With advances in inorganic membrane research, flexible, or bendable electronics can be fabricated from more traditional inorganic materials. For example, the research team led by Dr. Zhenqiang (Jack) Ma of the University of Wisconsin-Madison, developed super-flexible silicon chips that can withstand impact and severe vibration. By adding pressure to the chips, Professor Ma and Professor Max Lagally have increased chip performance to speeds 50 times faster than previous efforts. Dr. Ma is also working on flexible photodetectors, or optoelectronics, which are applicable for high-speed photography. He relates the successes of his research to his progress with new forms of semiconductor material, particularly nanomembranes. The Air Force could have a number of new uses for his research with flexible electronics and optoelectronics, including compact antennae attached to airplane bodies and missiles, flexible sensors that detect mechanical changes, and 360-degree air surveillance applications. Dr. Gernot Pomrenke, the AFOSR Program Manager who supports this work, noted that this effort is a very timely and relevant area of research for the Air Force and DoD, as well as for the semiconductor material and device component industries. The ability to synthesize and manipulate extremely thin films of solid-state materials enables wholly new approaches for improving performance and reducing the size, weight and power in defense and commercial systems.[92]

Updateable, Holographic 3-D Displays (2006-present)

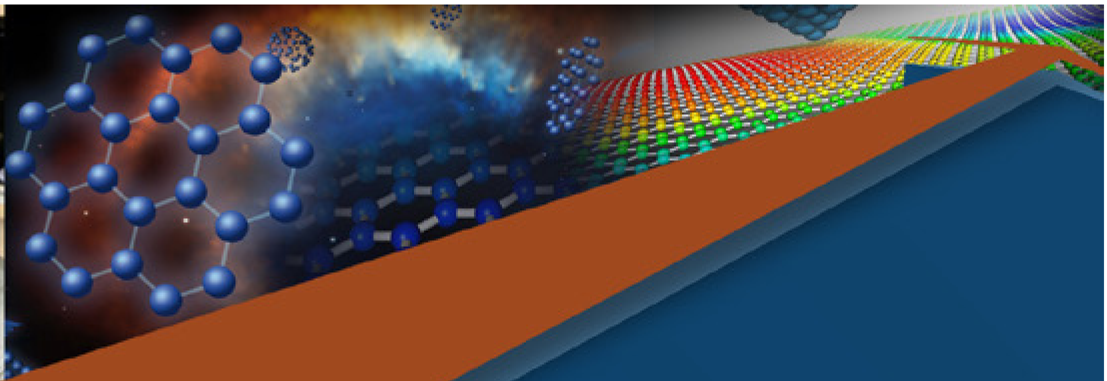
A group of AFOSR-funded scientists from the College of Optical Sciences at the University of Arizona, developed unique, updateable holographic three-dimensional (3-D) displays that can be used in military applications. This is the first-ever rewritable hologram for 3D image visualization. A team led by Dr. Nasser Peyghambarian is pioneering research using 3-D holographic images. Peyghambarian notes that, "3-D imaging allows a lot of data to be presented simultaneously, a task that is not possible with the use of 2-D pictures. Up until now dynamic, holographic 3-D images suitable for practical uses did not exist. Our newly developed displays exhibit memory and large size, which makes them stand out among other approaches to dynamic 3-D imaging. "Dr. Charles Lee, the AFOSR Program Manager for this project said, "This research is one of the fruits of continuing AFOSR support in the development of photorefractive polymers for the last 16 years." IBM first reported this polymer in the early 90s, during which time several AFOSR-supported groups were actively engaged in research in this area. Subsequent research has demonstrated the use of these materials for image correlation, wavefront correction and optical signal processing. Dr. Peyghambarian also noted that, "In practical military applications, the holographic 3-D images can be used for command and control–viewing battle space in nearly real time using realistic images that can be updated regularly at short intervals." The research team is able to achieve 3-D images by using holography to store the appearance of objects or scenes into thin films with the use of laser light, and they have gone one step further beyond static images by replacing fixed holographic storage materials with dynamic ones. Dr. Darrel G. Hopper and a team at the Air Force Research Laboratory Human Effectiveness Directorate at Wright-Patterson Air Force Base in Ohio is also exploring 'true 3-D' technologies for applications in air, space, and cyber command centers. Dr. Hopper uses the term 'true 3-D' to distinguish systems like the AFOSR updatable holographic effort at the University of Arizona. The next steps in this program are to increase the size of the 3-D displays, make them in color, and increase the writing speed of the images. The psychological aspects of 3-D viewing and the question of how humans interact with 3-D displays also needs to be examined. For example, it's believed that pilots may react and make decisions much faster if the information they are provided is 3-D, which is much more realistic compared with the usual 2-D displays they currently use," said Dr. Peyghambarian.[93]

Optical Parametric Oscillators Enable Aircraft Protection (2002-present)

Partially funded by AFOSR, a program at the Air Force Research Laboratory (AFRL) Sensors Directorate developed a compact Optical Parametric Oscillator (OPO), a device which converts an input laser wave into two output waves of lower frequency. This device, the so-called "Tower Laser," which used a nonlinear optical material in a cavity, pumped by a diode-pumped solid state laser system, offered the potential for wavelength tuning with extremely wide tuning ranges, in a compact device suitable for use on an aircraft. With this breakthrough, AFRL scientists demonstrated key concepts in missile spoofing utilizing an OPO with periodically poled lithium niobate (PPLN) as the nonlinear material. (PPLN, a breakthrough material, was itself the product of AFOSR-sponsored research at Stanford University.) This technology was quickly transitioned to a warfighter capability by Northrop Grumann, by being operationally employed in the Large Aircraft Infrared Countermeasures (LAIRCM) system that has a nearly 100% success rate spoofing shoulder launched missile attacks. The LAIRCM system automatically counters heat seeking missile systems—with no action required by the crew—by employing an active countermeasure that defeats the threat missile guidance system by directing a high-intensity modulated laser beam into the missile's infrared detector. The pilot is simply informed that a threat missile was detected and spoofed into changing course away from the aircraft. Users include the Air Mobility Command, the Air Force Special Operations Command and the Air Combat Command. At the end of 2012, the LAIRCM system was installed on 279 Mobility Air Force (MAF) and Air Force Special Operations Command (AFSOC) aircraft. A more recent AFOSR-sponsored research accomplishment, lithographically defined periodically oriented semiconductors, shows promise for wider infrared wavelength coverage and more efficient OPOs.[94]

Dynamic Network Analysis for Robust Uncertainty Management (DyNARUM) (2003-2004)

AFOSR (along with DARPA funding under AFOSR management), funded separate projects at United Technologies Research Center (UTRC), led by Dr. Andrzej Banaszuk; the University of California Santa Barbara (UCSB), led by Dr. Igor Mezic; and Caltech, led by Dr. Jerrold Marsden, in the area of analysis and control of complex dynamical systems. This research, in part, led directly to the discovery of new methods for passive mitigation of thermoacoustic instabilities in jet engines. This, and other related successes, were foundational to the UTRC, UCSB and Caltech team winning a 2006 DARPA project named Dynamic Network Analysis for Robust Uncertainty Management (DyNARUM) which was jointly managed by Dr. Carey Schwartz from DARPA and Dr. Fariba Fahroo from AFOSR. The DyNARUM team consisted of approximately 40 researchers from UTRC, UCSB, Caltech, Stanford, Princeton, Yale and the staff from two companies: AIMDyn and PlainSight. The objective of the DyNARUM project was to use new methods of ergodic theory, operator theory and spectral graph theory to develop methodology and tools for analysis and design of complex dynamical systems robust to uncertainty. Major accomplishments of the DyNARUM project were the introduction of new methods for quantifying uncertainty in dynamical systems that were orders of magnitude faster than previous methods, and the discovery of new, efficient Unmanned Aerial Vehicle (UAV) search methods which had near-linear scaling in the system size. The UAV planning and search methods developed by Caltech and UCSB, respectively, are currently used in UTRC's Autonomous & Intelligent Systems (AIS) program. AFOSR- and DARPA-sponsored research supported the transitions of these advanced technologies from academia to UTRC to application.[95]



"In recent decades, most research funding agencies have turned their back on curiosity-driven science and focus on funding areas promising immediate returns. This is their response to cries for modern equivalents of bread and circuses.

For all our sake, AFOSR has remained an island of sanity in the rising sea of idiocracy. AFOSR and its managers understand that to harvest economic fruits, one needs to do sowing first, sometimes many decades earlier. The chain from blue-sky research to consumer products is long, obscure and slow - but destroy the basics and the whole chain will collapse.

On your 60th anniversary, many thanks for keeping the candle lighting our way to new knowledge alive!"

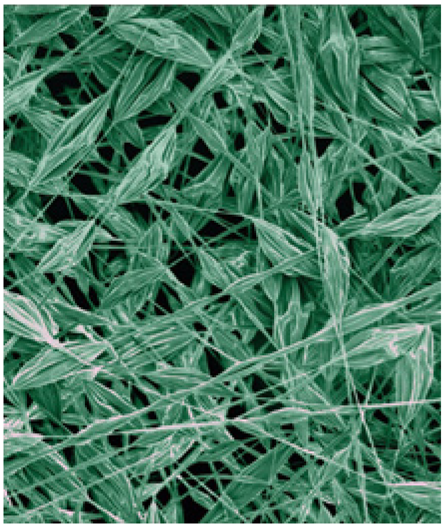
Professor Andre Geim, University of Manchester, Great Britain

Graphene (2008-present)

Professors Andre Geim and Konstantin Novoselov, from the University of Manchester, Great Britain, won the 2010 Nobel Prize in Physics for their pioneering research in graphene, which they first isolated in their seminal work of 2004 and 2005. AFOSR's European Office of Aerospace Research (EOARD) has funded their work to further the promise of graphene since 2008. Geim and Novoselov demonstrated graphene's remarkable qualities as the thinnest material in the universe and quite possibly the strongest ever measured. In addition to those amazing characteristics, its charge carriers–that is, the electrons that transport the electric charge in an induced electric current–exhibited the highest intrinsic mobility with zero effective mass, and can travel micron distances without scattering at room temperature. Graphene boasts multiple record electric and mechanical properties including the highest sustainable electric current, one million times copper; the highest thermal conductivity and mechanical strength both exceeding diamond, while at the same time it's the thinnest material possible at one atom thick, and still stretchable, flexible, and impermeable. Some scientists have predicted that graphene could one day replace silicon - which is the current material of choice for transistors. It could also yield incredibly strong, flexible and stable materials and find applications in transparent touch screens or solar cells. EOARD has aggressively followed up on this program, as have many others within the DoD research community.[96]

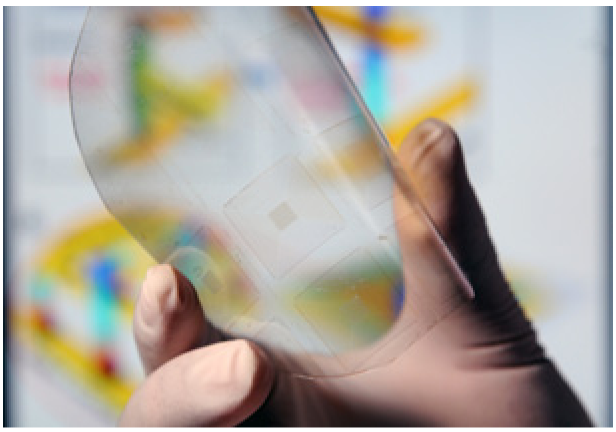
2000's

Super Oil Repellent Surfaces Research against Chemical/ Biological Agents, Leaks and Coffee Stains (2006-present)



AFOSR has funded investigations into super oil repellent surfaces because of their potential utility in cleaning up jet fuel spills and protecting aircraft or rocket parts from fuel absorption. Massachusetts Institute of Technology professors of engineering, Drs. Gareth H. McKinley and Robert E. Cohen have been exploring man-made and natural surfaces that keep gasoline and oil from soaking in and spreading out over a surface. The challenge is the low value of the surface tension of many oils, which makes them spread over surfaces very easily. Surface tension is a measure of the attraction between molecules of the same composition. The researchers' goal is to design new solid surfaces with very low interfacial energies that can repel oily liquids. Dr. McKinley noted that, "Nature has developed a lot of methods for waterproofing, but not so much oil-proofing." After studying the water repellent surfaces of lotus leaves, Drs. McKinley and Cohen created a microfiber fabric that can be deposited onto aircraft surfaces via a process known as electrospinning. The microfibers contain fluorinated nanoparticles, FluoroPOSS, which are synthesized by Dr. Joe Mabry and colleagues at Edwards Air Force Base, California. Dr. Charles Lee, AFOSR Program Manager for this project, noted that many people are addressing materials that repel water, but few are researching oil repellents, a research topic which is important for many Air Force systems. This collaborative research, involving scientists at MIT and Edwards Air Force Base, will be important for making future systems more maintenance free. The graduate student who worked on this project at MIT, Dr. Anish Tuteja, continued to conduct research in this area after becoming a faculty member at the University of Michigan. He developed fabrics that have opposite surface properties: one repelling water but not oil, and the other repelling oil but not water. Tuteja was able to demonstrate that this combination of fabrics acts as a filtering membrane by separating an emulsion of oil and water into its pure components simply by the force of gravity. This work may lead to protective coatings for airplane parts, which are vulnerable to fuel leaks, as well as the creation of new fuel-line gaskets that are immune to significant swelling when they absorb gasoline. In their latest research, the Tuteja team demonstrated surfaces that effectively perform as "chemical shields against virtually all liquids, using a nanoscale coating that is approximately 95 percent air, which in turn, repels liquids of any material in its class, causing them to literally bounce off the treated surface. This program is of particular interest to the Air Force and the Department of Defense, as it can be useful for self-cleaning surfaces (in particular, integral breathable protective Chemical/Biological Warfare defense in uniform clothing and sensor systems), improvement of thermal management efficiency in phase change cooling systems, fuel purification and the control of oil and fuel leakages in rockets and airplanes. Not to mention, protection against the everyday coffee spill.[97]

Transparent Transistors (2005-2009)



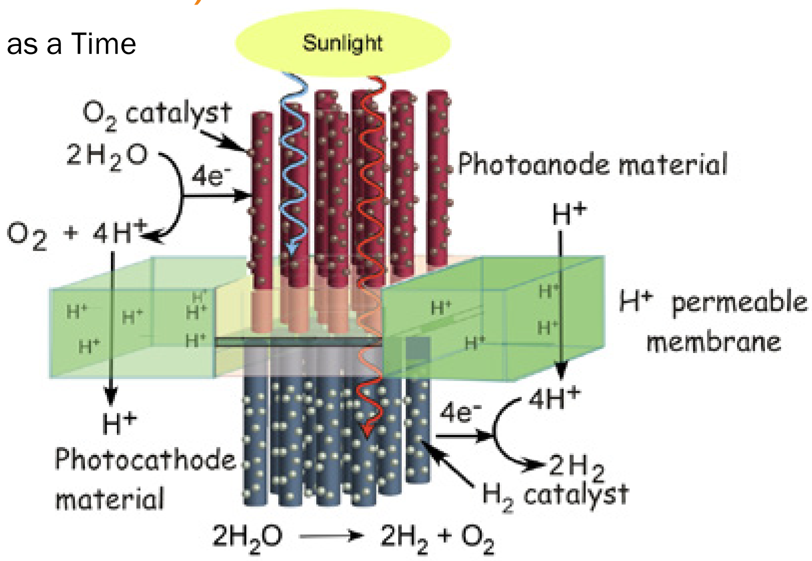
Air Force Research Laboratory scientists have demonstrated world-record performance of transparent transistors created from thin-film nanocrystalline zinc oxide which can function, undetected, on clear surfaces such as glass or plastic. Lead investigator Dr. Burhan Bayraktaroglu of AFRL's Sensors Directorate and his team are responsible for developing and testing these transparent transistors under support from AFOSR. A combination of high channel mobility, mechanical flexibility and high optical transparency at room temperature make the transparent transistors excellent candidates to support a wide range of future Air Force electronics needs and applications. Dr. Kitt Reinhardt, the initial AFOSR Program Manager for this effort, said potential applications include: video image displays and coatings for windows, visors and windshields; electrical interconnects for future integrated multi-mode, remote sensing, focal plane arrays; high-speed microwave devices and circuits for telecommunications and radar transceivers; and semi-transparent, touch-sensitive screens for emerging multi-touch interface technologies. Another attractive aspect of this new type of thin film transistor is that the processing technology used to fabricate the devices is relatively simple and is compatible with inexpensive plastic and flexible substrate technology. The AFRL team found that the trick to controlling the conductivity and transparency of the devices is optimizing the size and density of the zinc oxide nanocrystals. They have demonstrated films that are 90 to 95 percent transparent, have metal-like electrical conductivities and can withstand high temperatures for long periods without degrading. Dr. Bayraktaroglu and his team have used these devices to demonstrate the world's first thin-film microwave transistor operating up to 10GHz and 100X faster than any other thin film transistor. This work is continuing towards the goal of achieving 100GHz operation using finer lithography features and 2D electron gas at the thin film heterojunctions of ZnO and MgZnO. They also have perfected the application of zinc oxide films onto various surfaces using a special technique called pulsed laser deposition, which employs an ultraviolet laser beam to remove zinc oxide nanocrystals from a source, and deposit them as a thin film on the desired surface. These films are then processed into field effect transistors and transparent conductors using standard lithography techniques.[98]

Communication Earplug Revolutionizes Hearing Protection (2000-2012)

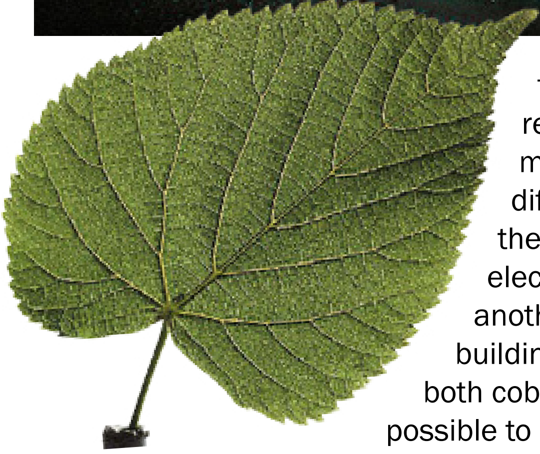
AFOSR-sponsored research has led to a communication earplug that revolutionizes hearing protection for Air Force pilots and flight crews, and could substantially reduce hearing loss and improve radio communication. This breakthrough research, led by Dr. Laura Ray of Dartmouth College, enabled the researchers, engineers and product developers at Sound Innovations, Inc. to develop a new active noise reduction system, which is at the heart of the new earplug design. The new device is expected to impact the work of active-duty military personnel by protecting and enhancing their hearing, allowing clear, two-way communication in noisy environments and enabling them to effectively listen to sounds from a distance. Dr. Ray worked out the mathematics to successfully conjoin noise control algorithms for the first time in a highly stable, hybrid system. This scientific breakthrough enables a much more robust approach to noise cancellation for the acoustically dynamic conditions encountered around aircraft engines," said Dr. Willard Larkin, AFOSR Program Manager for the project. "One of the primary challenges was to develop an electronic module for the earplug that could operate for 15 to 20 hours on AA batteries. We were able to use cutting-edge processor technology for developing a lower power electronics module," said Professor Ray. The earplug has high fidelity audio for clear speech, wide frequency range, light head-borne weight and replaceable ear-tips. It is stored in a small pouch that is attached to an airman's flight vest and delivers communication signals through the earplugs, which are worn under the helmet. The product was tested for design verification, evaluated for operational use and then the first generation of earplugs was flight tested at over a half dozen Air Force bases. In the interim, Sound Innovations, Inc. finalized the second generation design which has reduced power consumption, size and weight. Second generation prototypes are currently in field testing for commercial application.[99]

2000's

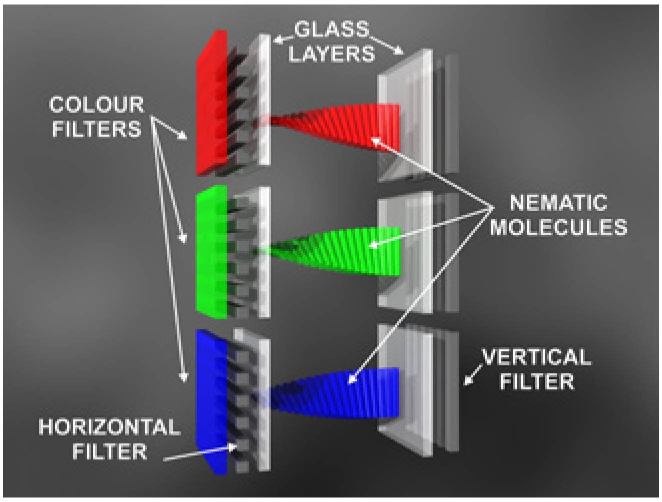
Artificial Photosynthesis (2009-2012)



One AFOSR-funded program was included as a Time Magazine "Innovation of the Year" for 2011. The news media has paid a great deal of attention to Dr. Daniel Nocera's breakthrough research in artificial photosynthesis--and with good reason. This technology has the potential to power an entire building for one day using only a few gallons of water and light energy from the sun. Solar energy could be a powerful solution to the energy needs of the future for both military and commercial entities, but as Dr. Nocera points out, power is needed all the time, not just when the sun is shining. Therefore, he and his research team at the Massachusetts Institute of Technology investigated new methods to store solar energy. Dr. Nocera readily admits that this is not a new concept, but the key to his research has been finding a technique that is cheap, efficient and easy to manufacture. After ruling out several lower energy options, Dr. Nocera's team chose to pursue photosynthesis, which naturally stores energy when splitting the bonds of water to produce oxygen and nature's chemical equivalent of hydrogen, NADPH. Using this model, he sought to develop an artificial photosynthesis that split water molecules into oxygen and molecular hydrogen (rather than NADPH) without the costs and harsh conditions that accompany existing commercial electrolyzers. Support from AFOSR enabled Dr. Nocera to conduct the basic research necessary to make this possible. Using cobalt-based oxide as a catalyst and phosphate as a proton acceptor, Dr. Nocera demonstrated a method for splitting water into oxygen molecules under environmentally friendly conditions. He then invented a Nickel-based metal alloy to turn the remaining protons and electrons into hydrogen. These catalysts are then affixed to Silicon as layers to produce the artificial leaf. In a presentation at AFOSR, Nocera expressed great pride in how easily this method can be prepared, saying that he often invites reporters and other interested parties into his lab to perform the experiment themselves. In the water-splitting experiment, the team places the leaf in a glass of phosphate-buffered water. When held up to sunlight, oxygen evolves from one side in a thin amorphous film containing the cobalt layer and hydrogen evolves simultaneously from the other side. Because the catalytic film forms in situ, or in the reaction mixture, a self-repair mechanism is implied. In this case, meaning that as oxygen evolves, cobalt is thought to cycle through different oxidation states as it attaches to phosphate and then to the electrode. The results indicate that any cobalt that falls off the electrode appears to reattach to another phosphate, activating it for another catalytic cycle. The ultimate goal of this research is to have buildings serve as their own power stations. Given the ready availability of both cobalt-phosphate catalysts and solar-generated electricity, it would be possible to use any excess daytime electricity to split water into hydrogen and oxygen. These products could be immediately stored and then recombined at night with fuel cells to power buildings as well as plug-in ground vehicles.[100]

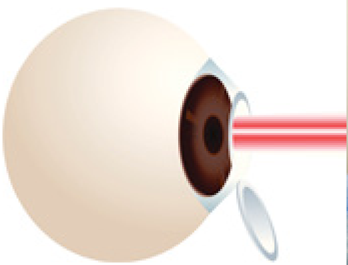


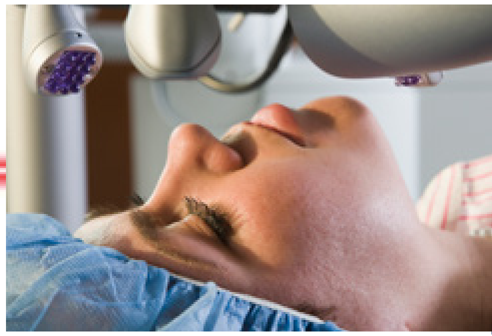
Ultra-small Displays: The Next Generation of Color Filters (2009-2013)

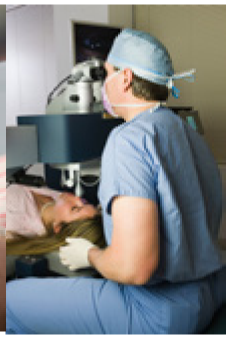


With AFOSR support, Dr. Jay Guo and his team at the University of Michigan, have created the smallest pixels available that will enable LED projected and wearable displays to be more energy efficient with significantly more light manipulation, and all on a display that may eventually be as small as a postage stamp. This latest nano-structuring technology for the Air Force includes a new color filter made of nano-thin sheets of metal-dielectric-metal stack, which have perfectly-shaped slits that act as resonators. They trap and transmit light and transform the pixels into effective color filtering elements. The pixels created from this technology are ten times smaller than what are now on a computer monitor and eight times smaller than ones on a smart phone. They use existing light more effectively and make it unnecessary to use polarizing layers for liquid crystal displays (LCDs) by employing nano-photonic devices using plasmonic structures. They enable the backlighting on the LED to be used more efficiently. Prior to this technology, LCDs had two polarizing layers, a color filter sheet, two layers of electrode-laced glass and a liquid crystal layer, but only about five percent of the backlighting reached the viewer. In the near future, the scientists are expecting to use nano-imprint lithography to begin making the next generation of color filters. According to AFOSR Program Manager, Dr. Charles Lee, many defense and aerospace applications require unique imaging techniques and compact systems, and over the last several years plasmonics has become a significant research area to explore new capabilities for such systems.[101]

Optical Coherence Tomography (2001-present)







In 1999, in the form of Program Manager Dr. Howard "Howie" Schlossberg, AFOSR took over, from the Office of Naval Research, the management of the Medical Free Electron Laser (MFEL) program (now known as the Military Photomedicine Program (MPP)), for the Office of the Secretary of Defense. Studying laser and optical technologies for medical applications, the focus of MFEL and MPP has been on diagnosing and treating wounded military personnel, with significant spin-off civilian applications often further funded by the National Institutes of Health or commercial companies. One significant outgrowth of MFEL program research is the rapid advancement, particularly in speed, of a technology which AFOSR funding invented: Optical Coherence Tomography (OCT). In 2002, OCT was described as, "A new optical imaging tool that could have profound effect on how images are created for use in medical diagnostics, materials science and microscopy....providing high-resolution, cross-sectional imaging similar to ultrasound, but using light.....for image resolution one to two orders above ultrasound." Today, OCT is the standard of care in diagnosing eye disease. It is also becoming indispensable in diagnosing and understanding cardiac disease, understanding diseases of the airway—including early diagnosis due to smoke inhalation—as well as burn and eye trauma injuries. Given the high mortality from smoke or chemical inhalation injury, OCT has proven exceedingly beneficial as it enables early detection, and therefore treatment, of tracheal inflammation via high resolution three dimensional imaging.[102]

Ultrahydrophobic Coatings (2003-2010)

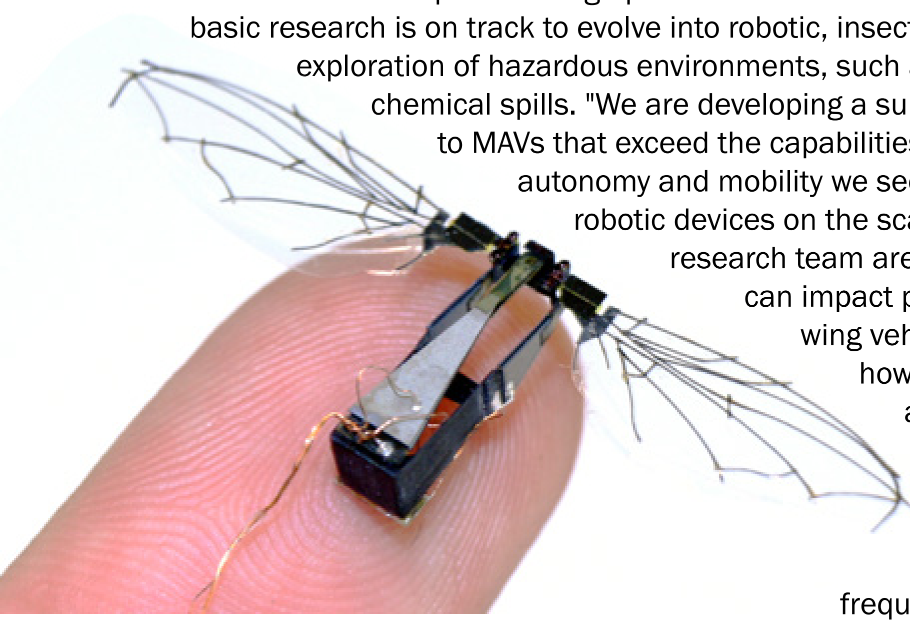
In 2003, AFOSR Program Manager Dr. Hugh DeLong, funded Dr. C. J. Brinker of the University of New Mexico and Sandia National Laboratories, to research "Biocompatible and Biomimetic Self-Assembly of Functional Nanostructures." One of the end results of this effort was the application of nano-assembly techniques to create a unique ultra-hydrophobic coating of an aircraft surface that effectively repels water. This approach was inspired by the Lotus flowers' ability to "self-clean" its leaves. This research combines nanomaterials (fluorine nanosphere polymers) and low surface energy to prevent water from reaching the metal surface. The Department of Defense spends billions on corrosion control, and 30% of that cost could be reduced simply through better materials design. In order to produce and apply a coating with ultra-hydrophobic, or extremely water-repellent, properties, the Brinker Nanostructures Research Group at the University of New Mexico and Sandia National Laboratories had to control coating roughness and surface chemistry on a small scale. The team, already known for their breakthroughs in aerogel thin film processing, drew from that research to develop a simple method for depositing the coating on every contour of a surface by spraying, spinning or dipping. Dr. Brinker explained that by a simple modification of a chemical precursor, the team reversed the shrinkage that typically occurs as a coating dries. Instead, it springs back, creating a nanoporous surface with super water-repellant properties. In addition to keeping water away, the researchers also are using this technology to design a patterned surface that combines extremely water-repellent and water-absorbent areas to draw water out of humid air. This application -- modeled after the Namib Desert beetle -- could provide a new method for collecting water without the use of energy and could benefit troops in areas where water is scarce. In addition, the self-cleaning properties of these surfaces also offer an interesting side benefit in chemical and biological defense: because of the contact angle between the water droplet and the surface, particulate tends to get trapped in the rolling drop and is automatically removed from the surface. Currently, materials that have been contaminated with chemical/biological agents have to be sprayed with harsh cleaning agents which can harm the material (aluminum aircraft, for example) during the decontamination process. Self-cleaning coatings would allow maintainers to spray a surface with water to remove the offending agents. Applications in the textile, automotive, aircraft, ship and medical device industries would be significant. The prospect of producing surfaces that repel water have huge opportunities in the area of corrosion inhibition for metal components, antifouling for marine vehicles, provide chemical and biological agent protection for clothing, and other applications. Protection of materials from water damage alone would provide significant savings in maintenance costs and extend the lifetime of current equipment.[103]

An Environmentally Friendly Aluminum and Ice Propelled Rocket (2007-2009)

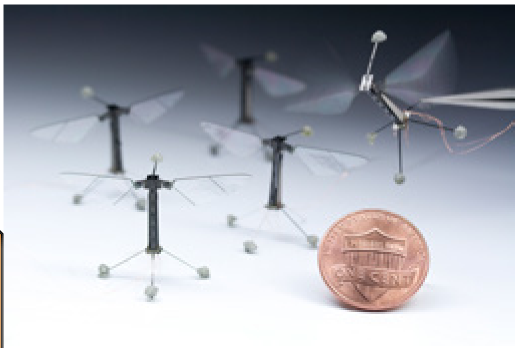
AFOSR has been involved with propulsion programs since its founding in 1951. The goal: move more weight cheaper than before. An AFOSR-funded effort not only achieves that goal, but does so in a much more environmentally friendly way. In August 2009, a rocket propelled by a novel propellant, consisting of a nanoscale aluminum and ice mixture, raced into the sky for the first time. This successful flight research was aimed at the development of advanced propellants, and was co-funded by AFOSR and NASA. The environmentally-friendly, safe propellant employed in this launch was comprised of aluminum powder and water ice (ALICE), a green propellant which produces benign gaseous hydrogen and solid alumina, that can be stored in the cold of space for long periods. This was a collaborative team effort, consisting of Drs. Steven F. Son and Tim Pourpoint of Purdue University, Rich Yetter and Grant Risha of Pennsylvania State University, and Vigor Yang of Georgia Tech. Dr. Son noted that the success of the flight can be attributed to, "...a sustained collaborative research effort on the fundamentals of the combustion of nanoscale aluminum and water over the last few years." Dr. Mitat Birkin, the AFOSR Program Manager for ALICE, said that previous attempts to make aluminum and water fuels foundered on the size of the aluminum particles used; what is new here is "nano-aluminum particles that are completely different from anything that has been done before." Earlier efforts used aluminum powder particles the size of a micron, which is about 100 times smaller than the width of a human hair. Micron-sized particles must be heated to 2,400 degrees Kelvin — about 3,860 degrees Fahrenheit — to ignite. Nano particles are 1,000 times smaller and will ignite at half that temperature. NASA Chief Engineer Mike Ryschkewitsch, based at NASA Headquarters in Washington, commented that the ALICE, "... collaboration has been an opportunity for graduate students to work on an environmentally-friendly propellant that can be used for flight on Earth and used in long distance space missions, and these types of university-led experimental projects encourage a new generation of aerospace engineers to think outside of the box and look at new ways for NASA to meet our exploration goals." ALICE is generating excitement among the researchers because it has the potential to replace some liquid or solid propellants. It is a promising propellant energetically. Theoretically, when it is optimized, it could have a higher performance than a conventional propellant, and its performance can be improved by 25 percent with the addition of other oxidizers and fuel enhancements.[104]

Micro-Robotic Fly (2007-2012)

An AFOSR-sponsored researcher, Dr. Robert Wood of Harvard University, is leading the way in what could become the next phase of high-performance Micro Air Vehicles (MAVs) for the Air Force. His basic research is on track to evolve into robotic, insect-scale devices for the monitoring and exploration of hazardous environments, such as collapsed structures, caves and chemical spills. "We are developing a suite of capabilities which we hope will lead to MAVs that exceed the capabilities of existing small aircraft. The level of autonomy and mobility we seek has not been achieved before using robotic devices on the scale of insects," said Wood. Wood and his research team are trying to understand how wing design can impact performance for an insect-size, flapping-wing vehicle. Their insights will also influence how such agile devices are built, powered and controlled. "A big emphasis of our AFOSR program is the experimental side of the work," said Wood. "We have unique capabilities to create, flap and visualize wings at the scales and frequencies of actual insects." The researchers



are constructing wings and moving them at high frequencies recreating trajectories similar to those of an insect. They are also able to measure multiple force components, and they can observe fluid flow around the wings flapping at more than 100 times per second. Performing experiments at such a small scale presents significant engineering challenges beyond the study of the structure-function relationships for the wings. "Our answer to the engineering challenges for these experiments and vehicles is a unique fabrication technique we have developed for creating wings, actuators, thorax



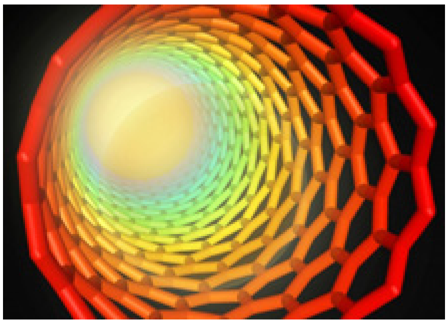
and airframe at the scale of actual insects and evaluating them in fluid conditions appropriate for their scale," he said. They are also performing high-speed stereoscopic motion tracking, force measurements and flow visualization; the combination of which allows for a unique perspective on what is going on with these complex systems. Begun under AFOSR Program Manager Dr. Rhett Jefferies in 2007, and then transitioned to AFOSR Program Manager, Dr. Douglas Smith, the “Comprehensive Study of Aeroelasticity in Flapping-Wing MAVS” program, continued to be funded under a Young Investigator Program through 2012. Much of the basic research has now transitioned to an applied technology U.S. Army Micro-Autonomous Systems and Technology (MAST) program.[105]

Treating Battlefield Injuries with a Laser (2008-present)

Airmen's traumatic battlefield injuries may be more effectively treated by using a new light-activated technology developed as a result of research managed by AFOSR and supported by funds from the Office of the Secretary of Defense. Pioneered by Dr. Irene Kochevar and Dr. Robert Redmond, Harvard Medical School professors and Massachusetts General Hospital Wellman Center researchers, this technology is centered on the treatment of war injuries employing a process called Photochemical Tissue Bonding (PTB), which can replace conventional sutures, staples and glues in repairing skin wounds and surgical incisions, reconnecting severed peripheral nerves, blood vessels and tendons, as well as incisions in the cornea. Pilot clinical studies have demonstrated that this technology produces better healing and functional outcomes than the same

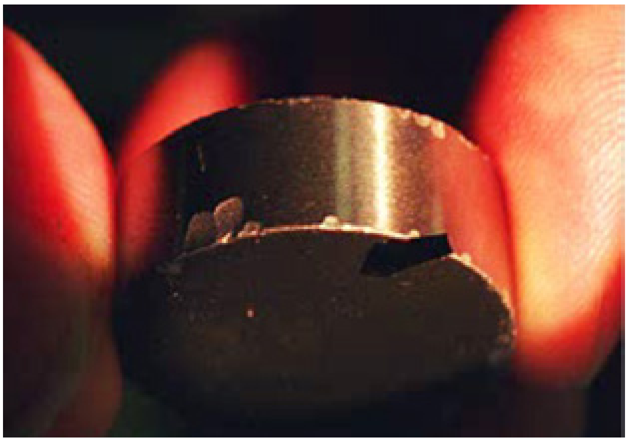
wounds that were treated with conventional materials. Importantly for military applications, lower skill levels are also required than with conventional procedures. The process of creating the bonding or nanosutures is accomplished by applying a dye to the wound, or damaged tissue, and then exposing it briefly to green light. The dye absorbs the light which helps it to molecularly bond proteins on the tissue surface. No glues, proteins or other materials are used that might stimulate an inflammatory response, and an immediate, water-tight seal is formed between the tissue surfaces leading to reduced inflammation in the near term and less scar formation in the long term. The use of film wraps and stents to assist bonding has been successfully used, with very good results achieved using amniotic membrane material. Dr. Kochevar noted: “We have demonstrated that this technology is very helpful in medicine for the Air Force because it produces better healing and functional outcomes than the same wounds that were treated with conventional sutures.” The researchers are continuing to evaluate the effectiveness of the new technology with military collaborators and carrying out studies to enhance its effectiveness in theater. Currently, they are seeking a shorter treatment time that yields an even stronger bond. Clinical trials are being planned for the various applications of PTB.[106]

Environmentally Safe Fuel Cells (2009-present)



Funded by AFOSR and the National Science Foundation, Massachusetts Institute of Technology researchers are exploring a new technology, called a thermopower wave, that may convert chemical energy to fuel cells for micro-machines, sensors and emergency communication beacons. The promising technology is generating attention because it is 100% non-toxic, saves energy, and can also create a significant amount of power in tiny batteries—up to ten times as much as commercial batteries according to Dr. Michael Strano, MIT Associate Professor of Chemical Engineering. The key components of these devices are tiny, molecular wires called carbon nanotubes, or CNTs, which when coated with fuel can conduct heat and create an energy wave in the process. These waves may form the basis of new types of fuel cells that convert condensed liquid fuel into electrical energy in a continuous manner. A major challenge that the researchers faced was activating the devices without using too much energy. As a result, they explored different methods, including lasers, electrical sparks and direct heating from a resistor before they discovered the thermopower wave. Another important step for the researchers is to develop refueling systems that can cover the CNTs with more fuel so that the devices can be used more than once, greatly expanding their potential applications.[107]

Plastic Magnets (2002-present)



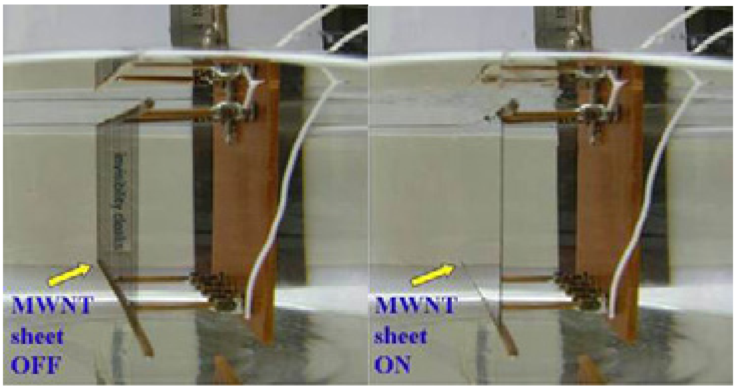
Physicists are using carbon-based molecules to create plastic magnets from organic materials that are capable of absorbing electromagnetic radiation. This technology benefits the Air Force's warfighting effort by detecting weapons hidden in clothing or in packages. Featured on the History Channel's show Modern Marvels, this AFOSR-funded research, led by Dr. Arthur Epstein, Professor of Physics and Chemistry and director of The Ohio State University's Institute for Magnetic and Electronic Polymers, may even lead to the creation of improved electronic circuits that can find hidden flaws in electronic circuitry. These magnets are "organic" because they are formed from molecules based on carbon, hydrogen and nitrogen. They form magnetic films on electrical insulators such as glass and Teflon, and electronic materials such as silicon and gold. Because they are magnetic at room temperatures -- even up to 250 degrees Fahrenheit -- they may be used in a variety of environments. Epstein observed, "These films absorb electromagnetic radiation such as microwaves and terahertz rays, or T-rays, which can be used to look through wrappings for weapons. While they can image like x-rays, they have the important advantage of causing little or no harm to living tissue in contrast to damage caused by x-rays." Plastic magnets share properties with conventional magnets and among their unique properties are the ability to control the magnetism with light and to have the 'spins' of the electrons be pointed the same direction. This is a rare property of matter that has never before been found in a semiconductor until now. When plastic magnets were initially produced by Epstein's colleague, Dr. Joel S. Miller of the Department of Chemistry at the University of Utah, they were so unstable they were flammable in the air. "By coating the magnets with a nonmagnetic and non-conducting polymer, we have been able to make them more stable. In fact, they may now be in ambient air, which is a gaseous mixture made up of nitrogen and oxygen, for hours without becoming combustible or decreasing their performance as detectors or electronic and magnetic materials," Dr. Miller noted. Epstein remains optimistic about the future of plastic magnets and their use in Air Force technology because his research is continuing unabated and the chemistry of the materials is evolving so that magnetic, electronic and photonic properties will continue to improve. Dr. Charles Lee, AFOSR Program Manager, has funded this unique program beginning in 2002.[108]

2000's

Situational Awareness with Smart Satellite Imagery (2003-2009)

Researchers from the University of Southern California (USC) improved Air Force situational awareness with software that presents vast amounts of map data in a more manageable format for commanders in theater. Using basic research funding from AFOSR, Dr. Craig Knoblock and his team developed a computerized method for aligning maps with satellite imagery. The resulting format combined the timeliness and visual appeal of photographs with the detailed information found on maps. While the idea was not new, the old method required a person to identify a set of control points manually for registering a map with an image. This process, though tedious, was able to account for a variety of map designs and their inherent differences. The key to Knoblock's AFOSR-funded work was finding an automated method that could also account for these differences. The team initially looked for the most comprehensive way to process maps for gathering needed data. Next, they investigated how to relate that extracted data to satellite images. The resulting solution uses road vector data as the metaphorical glue binding the two formats together. "The idea is to automatically extract the road intersections on a map and use the layout of those intersections to find the corresponding area on the satellite imagery," Knoblock explained. The success of this basic research led Knoblock and his team at USC to create a spin-off company called Geosemble Technologies. In-Q-Tel took over funding when AFOSR support ended in 2009, and Geosemble was acquired by TerraGo Technologies in June 2012. This basic research effort resulted in Air Force and DOD planners having the ability to integrate maps quickly and automatically with the latest aerial and satellite imagery for a given area, thereby creating context and situational awareness for better and faster decision-making and operations in the field.[109]

Transparent Material Breakthrough (2005-present)



A program co-funded by AFOSR was chosen by Time Magazine for its List of Best Inventions of 2011. Drs Ali Aliev, Yuri Gartstein and Ray Baughman, of the University of Texas at Dallas (UTD), succeeded in producing what is technically referred to as the "mirage effect from thermally modulated transparent carbon nanotube sheets," or, as some in the popular press have termed it: an 'invisibility cloak'." The key to this breakthrough are carbon nanotubes—the successful result of another ongoing AFOSR-funded UTD program—that have the ability to disappear when rapidly heated. In reality, this effect is due to photothermal deflection, or a mirage effect, quite similar to what a driver may experience when a highway in the distance becomes so hot that a section of the road may look like a pool of water. This is due to the bending of the light around the hot road surface wherein the driver actually sees the reflected sky in place of the pavement. The carbon nanotubes create much the same effect when heated. AFOSR funding for this program was critical in enabling nanotube sheet fabrication which offers key advantages for photothermal deflection which permits the transparency effect to take place. This unique characteristic of nanotube sheets may one day result in applications such as photo-deflectors and for switchable transparency materials, as well as their use as thermoacoustic projectors and sonar. Research continues on this unique effort under a portfolio managed by AFOSR Program Manager Dr. Byung-Lip ("Les") Lee.[110]

"My students and I owe a great debt to AFOSR. Because of continuous support from Dr. Howard Schlossberg of AFOSR, for the past 34 years, we have been able to pursue research avenues in lasers and plasmas that defy quick solutions and yet have considerable promise for DoD and commercial applications. As a result, 44 individuals have received the Ph.D. degree with AFOSR support and many have made enormous contributions to military systems, commercial products, and advances in research. Companies have been formed that now manufacture lighting and water purification systems that have not existed in the past. The sustained support of AFOSR for investigators throughout this country is a crucial factor in the discovery and development of technologies that undergird the force capabilities of the DoD but also serve as the basis of entirely new products and industries that provide the future for the U.S. economy.

Congratulations, AFOSR, on your 60th birthday! My deepest thanks for your support and my hope is that the next 60 years are as productive, and beneficial for our country, as have the first six decades."

Dr. Gary Eden, University of Illinois

Micro-Cavity Arrays: Lighting the Way to the Future (2005-present)

A research team funded by AFOSR has pioneered the use of micro-plasmas in a revolutionary approach to illumination, and Drs. Gary Eden and Sung-Jin Park of the University of Illinois, Urbana-Champaign, have founded Eden Park Illumination, Inc. to bring this new lighting technology to the world. Just as in a fluorescent light, a micro-cavity array is energized by an applied voltage. By successfully confining that plasma in parallel rows of micro-cavities within thin sheet materials, Eden and Park ultimately arrived at various implementations of micro-plasma arrays, some of which result in inexpensive, wafer-thin, and very flexible sheets of light. The key to these light arrays are the micro-cavities which are formed within the flexible sheets. In one of the most important implementations, the one being developed by Eden Park Illumination, a sheet of aluminum foil is placed in an anodizing bath. By controlling the bath parameters, its temperature, and the time of anodizing, large arrays of micro-cavities can be formed with near optimum shape and with automatically placed interconnecting aluminum electrodes. The largest array thus far contains a quarter million luminous micro-cavities. When A/C power is supplied through the almost invisible grid, the array bursts to life. The MCAs are ruggedized to a certain extent and have an ultimate thickness of about four millimeters, leaving you with a wafer that weighs less than 200 grams. This revolutionary advance in lighting offers many advantages: the array is thin, flat and small—a major contributor to efficiency; the fluorescent light tube has a stated efficiency of about 75 to 80 lumens per watt, by comparison, the efficiency of the MCA is over 90 percent; the MCA does not contain mercury—an environmental advantage. In addition, the array is fully dimmable while fluorescent lighting is not. The MCA also offers better color rendering, its components are fully recyclable, and it lasts up to 20,000 hours before failure. While the MCA is currently not as efficient as an LED, it runs much cooler and is far lighter. Special applications might include aircraft cockpit lighting and displays due to less weight, size and heat, as well as the flexibility to conform to cramped interior spaces. Tanks and other combat vehicles would offer an ideal application. Interior lighting for homes and offices could be transformed given the flexibility of the technology. Even the lowly refrigerator light could be in line for an upgrade. AFOSR Program Manager Dr. Howard Schlossberg has funded Dr. Eden's MCA work since 2005.[111]

2000's

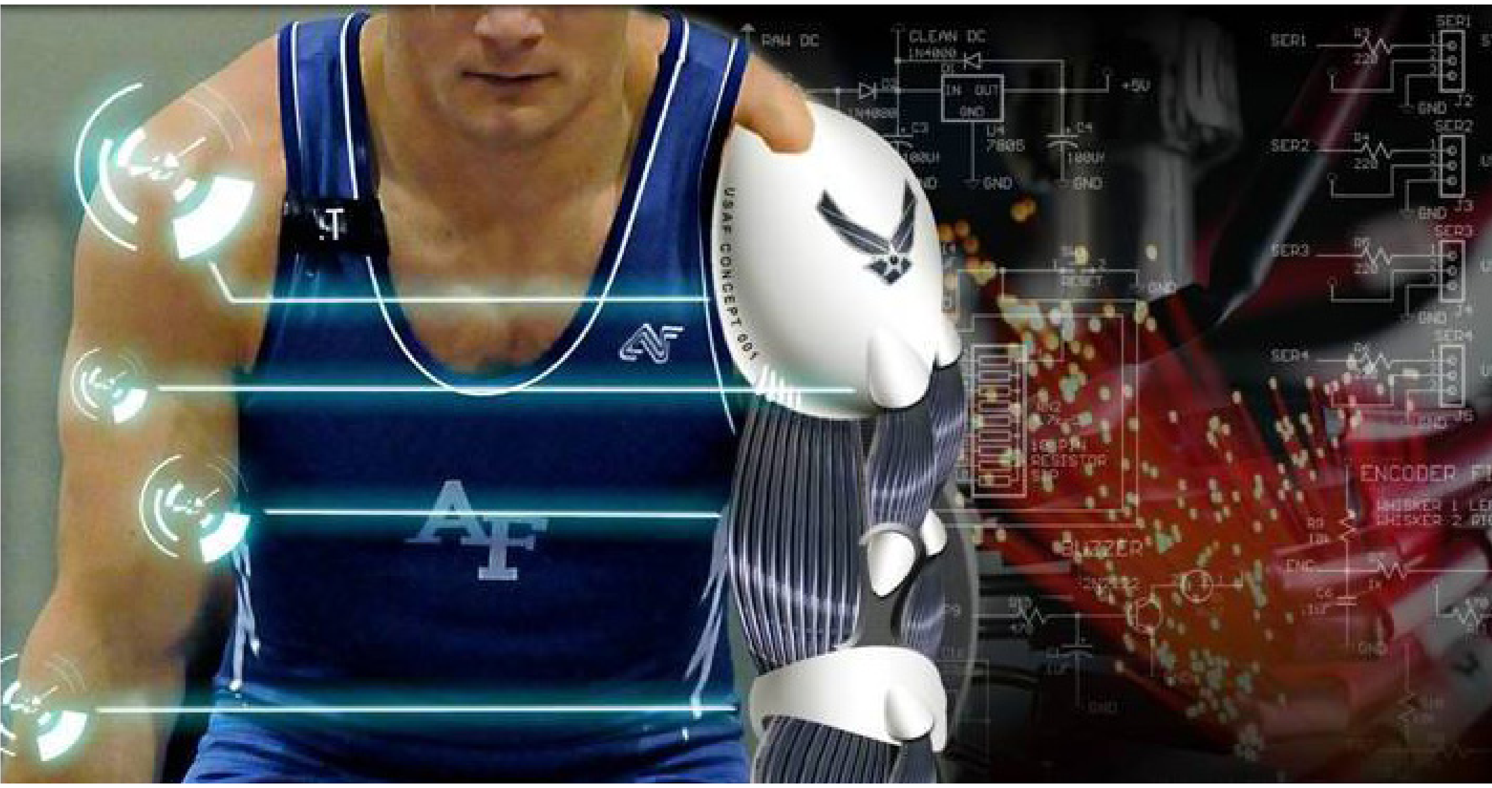
A 60th Anniversary Toast to the Spirit, Culture, and Success of AFOSR

Dr. Ray Baughman, University of Texas, Dallas

"AFOSR has critically strengthened America and helped make a safer and more scientifically enlightened world during the six decades that we here celebrate. A culture encouraging high-risk/high reward ideas, partnerships of ideas, and their meaningful evaluation and support is one reason for this success. The abilities of Program Managers to wisely guide and select comes from their deep understanding of the technological and underlying scientific needs of our country, which is drawn from interactions within all of DoD, industry, and far beyond. Encouraged and enabled teaming between researchers in universities, governmental laboratories, small businesses, and friendly countries has also been very important for providing advances.

Being even a decade older than AFOSR, I might not have another opportunity to express my debt to many Program Managers in AFOSR, and especially to Program Manager Dr. Byung-Lip ("Les") Lee. His review meetings for multiple projects are exciting - they bring together talented Priciple Investigators having expertise in diverse areas with wise scientists and technologists from government and industry. Deep trust and friendships develop here that encourage people to help each other. Les' support has been critically important for much that my teams do–benefits continue even from long competed projects that provide platforms for future work. For example, we are now applying advances on carbon nanotube sheets developed for Les to Navy projects on sheet-based thermoacoustic sound projectors (sonar and "Warn and Hail" speakers), to a NASA program on modifying aircraft boundary layers, and to industrially funded projects on aircraft composites and displays. Long term support by Les Lee has enabled our discovery of successive generations of artificial muscles, each fundamentally different and better than the last in some key feature. Many initially unplanned discoveries have resulted from his ongoing funding, like mirage invisibility cloaks and yarn-based artificial muscle thermoacoustic sound projectors that "sing as they work". Such AFOSR project work has been inspirational and life-changing for young people, including even our NanoExplorer high school students and our undergraduate students, who have co-authored associated patents and high impact publications as a result of their discoveries.

Happy Anniversary AFOSR! May you forever continue as a powerhouse for our nation's future that wisely guides and enables frontier research and development, provides the foundations for commercialization, strengthens our nation's workforce, and encourages scientific and technological partnerships between nations."



AFOSR-funded Research Leads to New Type of Artificial Muscle (2005-present)

Dr. Ray Baughman, director of the NanoTech Institute at the University of Texas, Dallas, and his team of researchers have been working on artificial muscles for more than twenty years. This pioneering work stems from an exploratory research program supported by AFOSR Program Manager, Dr. Byung-Lip "Les" Lee since 2005, whereby the team invented many new muscle types, including electrochemical carbon nanotube and conducting polymer muscles, as well fuel-powered muscles. The latter, powered chemically by alcohol or hydrogen, operate similarly to natural muscles, but they are limited in that they cannot function at extreme temperatures and have low efficiencies for energy conversion. Dr. Baughman's nano-based muscles, which are 30 times stronger than natural muscles, are made of very thin sheets of nanotubes (1/10,000th of the diameter of a human hair) that on a weight basis are "strong as steel" in one direction and as elastic as rubber in two other directions. These artificial muscles can also operate at extreme temperatures which makes them especially attractive for space applications. They are also being viewed as a means for endowing soldiers with super-human strength through the use of exoskeletons. Artificial muscles may also be used to actuate "smart skins," which would give Air Force aircraft the ability to change their appearance. "We want to use the carbon nanotube sheets to affect the boundary layers on Air Force micro air vehicles and even larger vehicles to provide a new type of controllability and increase flight efficiency," Baughman said. The most recent research by the Baughman and his international team from Australia, China, South Korea, Canada and Brazil, has resulted in new artificial muscles made from nanotech yarns and infused with paraffin wax can that can lift more than 100,000 times their own weight and generate 85 times more mechanical power during contraction than the same size natural muscle. The new artificial muscles are made by infiltrating a volume-changing "guest," such as the paraffin wax used for candles, into twisted yarn made of carbon nanotubes. Heating the wax-filled yarn, either electrically or using a flash of light, causes the wax to expand, the yarn volume to increase, and the yarn length to contract. "Because of their simplicity and high performance, these yarn muscles could be used for such diverse applications as robots, catheters for minimally invasive surgery, micromotors, mixers for microfluidic circuits, tunable optical systems, microvalves, positioners and even toys," Baughman said.[112]

AFOSR-funded Nobel Timeline

A Strong Legacy of Nobel Prize Winning Research

1950's

1955 PHYSICS
Polykarp Kusch, Willis Lamb
"precision determination of the magnetic moment of the electron and discoveries concerning the fine structure of the hydrogen spectrum"

1956 PHYSICS
John Bardeen
"co-invention of the transistor"

1960 CHEMISTRY
Willard Libby
"method to use carbon-14 for age determination in archaeology, genealogy, geophysics, and other branches of science"

1961 PHYSICS
Robert Hofstadter
"pioneering studies of electron scattering in atomic nuclei and for his thereby achieved discoveries concerning the structure of the nucleons"

1963 PHYSICS
Eugene Wigner
"contributions to the theory of teh atomic nucleus and the elementary particles, particularly through the discovery and application of fundamental symmetry principles"

1960's

1964 PHYSICS
Charles Townes
"fundamental work in the field of quantum electronics, which has led to the construction of oscillators and amplifiers based on the maser-laser principle"

1966 CHEMISTRY
Robert Mulliken
"fundamental work concerning chemical bonds and the electronic structure of molecules by the molecular orbital method"

1967 MEDICINE
Ragnar Granit
"discoveries concerning the primary physiological and chemical visual processes in the eye"

1967 PHYSICS
Hans Bethe
"contributions to the theory of nuclear reactions, especially his discoveries concerning the energy production in stars"

1967 CHEMISTRY
George Porter
"for studies of extremely fast chemical reactions, effected by disturbing the equilibrium by means of very short pulses of energy"

1968 CHEMISTRY
Lars Onsager
"for the discovery of the reciprocal relations bearing his name, which are fundamental for the thermodynamics of irreversible processes"

1969 PHYSICS
Murray Gell-Mann
"contributions and discoveries concerning the classification of elementary particles and their interactions"

1970 MEDICINE
Ulf von Euler
"discoveries concerning the humoral transmitters in the nerve terminals and the mechanism for their storage, release and inactivation"

1970's

1972 PHYSICS
John Bardeen, John Schrieffer
"theory of superconductivity, usually called the BCS-theory"

1973 PHYSIOLOGY/MEDICINE
Nikolass Tinbergen
"discoveries concerning organization and elicitation of individual and social behavior patterns"

1973 PHYSICS
Brian Josephson
"theoretical predictions of the properties of a supercurrent through a tunnel barrier, in particular those phenomena that are generally known as the Josephson effects"

1974 CHEMISTRY
Paul Flory
"fundamental achievements in the physical chemistry of macromolecules"

1976 CHEMISTRY
William Lipscomb
"studies on the structure of boranes illuminating problems of chemical bonding"

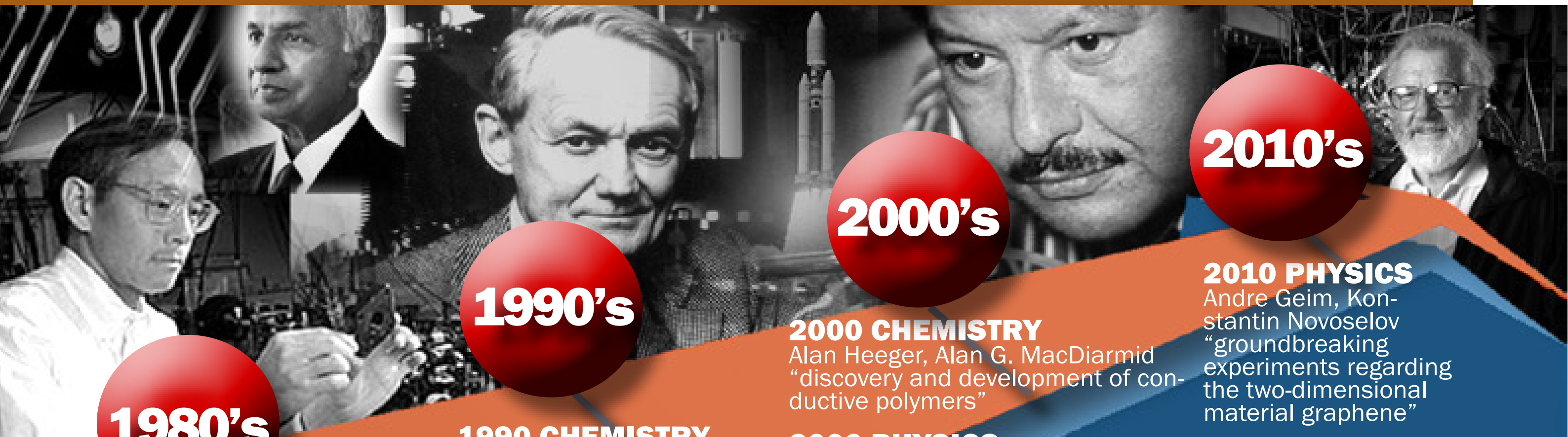
1977 PHYSICS
Philip Anderson, John Van Vleck
"fundamental theoretical investigations of the electronic structure of magnetic and disordered systems"

1977 CHEMISTRY
Ilya Prigogine
"contributions to non- equilibrium thermodynamics, particularly the theory of dissipative structures"

1978 ECONOMICS
Herbert A. Simon
"for his pioneering research into the decision-making process within economic organizations"

1979 PHYSICS
Sheldon Glashow, Stven Weinberg, Abdus Salam "contributions to the theory of the unified weak and electromagnetic interaction between elementary particles, including inter alia the prediction of the weak neutral current"

The Air Force Office of Scientific Research has created a strong legacy of Nobel Prize winning research. Since its establishment in 1951, AFOSR has sponsored 71 researchers who went on to become Nobel laureates. On average, these laureates received AFOSR funding 17 years prior to winning their Nobel awards. The accomplishments of these laureates demonstrate the astute ability of AFOSR Program Managers to choose world-class researchers to address Air Force requirements and advance Air Force programs. AFOSR has funded 36 laureates in Physics, 24 in Chemistry, eight in Physiology or Medicine, and three in Economics.[113]



1980's

1980 CHEMISTRY
Walter Gilbert
"contributions concerning the determination of base sequences in nucleic acids"

1981 PHYSICS
Nicolas Bloembergen, Arthur Schawlow, Kai Siegbahn
"contributions to the development of laser spectroscopy"

1981 CHEMISTRY
Kenichi Fukui, Roald Hoffman
"theories concerning the course of chemical reactions"

1981 MEDICINE
David Hubel, Thorsten Wiesel
"discoveries concerning information processing in the visual system"

1983 PHYSICS
Subramanyan Chandrasekhar, William Fowler
"theoretical studies of the physical processes important to the structure and evolution of the stars" and "theoretical and experimental studies of the nuclear reactions of importance in the formation of the chemical elements in the universe"

1986 CHEMISTRY
Yuan Lee, Dudley Herschbach, John Polanyi
"contributions concerning the dynamics of chemical elementary processes"

1987 CHEMISTRY
Donald Cram
"development and use of molecules with structure- specific interactions of high selectivity"

1988 PHYSICS
Melvin Schwartz
"neutrino beam method and the demonstration of the doublet structure of the leptons through the discovery of the muon neutrino"

1990's

1990 CHEMISTRY
Elias Corey
"development of the theory and methodology of organic synthesis"

1990 PHYSICS
Jerome Friedman, Henry Kendall
"pioneering investigations concerning deep inelastic scattering of electrons on protons and bound neutro ns"

1992 CHEMISTRY
Rudolph Marcus
"contributions to the theory of electron transfer reactions in chemical systems"

1995 CHEMISTRY
Mario Molina
"work in atmospheric chemistry, particularly concerning the formation and decomposition of ozone"

1996 CHEMISTRY
Richard E. Smalley
"shared award for the discovery of fullerenes"

1997 PHYSICS
Steven Chu
"development of methods to cool and trap atoms with laser light"

1998 PHYSICS
Daniel Tsui
"discovery of a new form of quantum fluid fractionally charged excitations"

1999 CHEMISTRY
Ahmed Zewail
"studies of the transition of chemical reactions using femtosecond spectrocopy"

2000's

2000 CHEMISTRY
Alan Heeger, Alan G. MacDiarmid
"discovery and development of conductive polymers"

2000 PHYSICS
Herbert Kroemer
"developing semiconductor heterostructures used in high-speed and opto-electronics"

2000 MEDICINE
Eric R. Kandel, Paul Greengard
"signal transduction in the nervous system"

2000 PHYSICS
Jack Kilby
"invention of the integrated circuit"

2001 PHYSICS
Wolfgang Ketterle
"jointly for the achievement of Bose-Einstein condensation in dilute gases of alkali atoms, and for early fundamental studies of the properties of the condensates"

2002 ECONOMICS
Daniel Kahneman
"integrated insights from psychological research into economic science, especially concerning human judgment and decision-making under uncertainty"

2002 CHEMISTRY
John Fenn
"for the development of methods for identification and structure analyses of biological macromolecules" and "for the development of soft desorption ionization methods for mass spectrometric analyses of biological macromolecules"

2003 PHYSIOLOGY/MEDICINE
Paul C. Lauterbur
"for discoveries concerning magnetic resonance imaging"

2005 PHYSICS
John Hall, Roy Glauber, Theodor W. Hansch
"contribution to the quantum theory of optical coherence and jointly for development of laser precision spectroscopy"

2005 CHEMISTRY
Robert Grubbs
"development of the metathesis method in organic synthesis"

2005 ECONOMICS
Thomas Schelling
"for having enhanced our understanding of conflict and cooperation through game-theory analysis"

2006 PHYSICS
George Smoot
"discovery of the blackbody form and anisotropy of the cosmic microwave background radiation "

2008 PHYSICS
Yoichiro Nambu
"discovery of the mechanism of spontaneous broken symmetry in subatomic physics"

2010's

2010 PHYSICS
Andre Geim, Konstantin Novoselov
"groundbreaking experiments regarding the two-dimensional material graphene"

2011 CHEMISTRY
Daniel Schechtman
"discovery of quasicrystals"

2012 PHYSICS
David Wineland
"for ground-breaking experimental methods that enable measuring and manipulation of individual quantum systems"

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