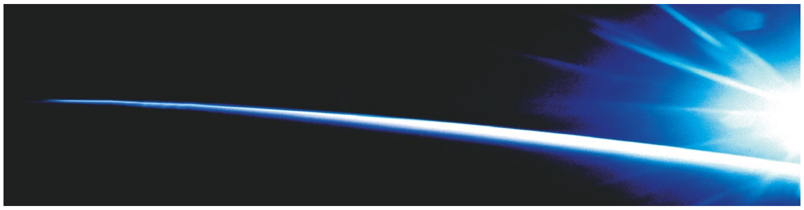
AIR FORCE OFFICE of SCIENTIFIC RESEARCH [AFOSR]
Manager of the Basic Research Investment for the Air Force



Research HIGHLIGHTS

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Basic Research: Giving Wings to Manned Flight

Manned flight will celebrate its 100th anniversary in December. It will also mark an occasion to pay homage to those aerospace science researchers who gave aviators their wings.

For over 50 years, the Air Force Office of Scientific Research (AFOSR) orchestrated many revolutionary new capabilities for the Air Force. In this centennial year of manned flight, it is appropriate to acknowledge the many contributions of basic research in the quest to fly higher (or lower), faster, safer, and easier – and not just for military benefit. While improving the air supremacy capabilities of the United States Air Force, AFOSR's many achievements have also led to significant improvements in commercial flight.

But manned flight itself would not have been possible without basic research. Orville and Wilbur Wright performed basic research to design their aircraft, even building their own wind tunnel to test new concepts. Following in their footsteps, AFOSR strives to improve on what these pioneers first created.

AFOSR was established in the early 1950s, just as the dawn of the jet age spawned a surge in research. To address the challenges presented by supersonic flight, AFOSR funded the work of Dr. Rudolph Kalman and Dr. Richard Bucy in the use of modern statistical methods to improve aerodynamic stability that was to become known as the Kalman filter. A basic building block in flight control, this filter remains an integral part of high-speed commercial and military flying vehicles.

In the 1950s, a related AFOSR effort in supersonic flight dealt with understanding and improving the capabilities of aircraft structures in this new flight envelope regime. One application of this research introduced favorable interference surfaces on supersonic military aircraft in the early 1960s to reduce drag and make engines in supersonic flight more efficient. Another basic research success, related to the study of shock wave/boundary layer interaction, led to the first accurate static pressure probe and speed indicator for use on the century series (F-100, 101, 102, 104, 105, 106) of Air Force aircraft.

Apollo 11 employed the Kalman filter to guide the lunar module to the moon's surface.

The flight pressure suit is standard equipment when flying the high performance F-16 fighter.

As newer jet aircraft designs pushed the performance envelope, stresses on pilots became more severe. In the late 1950s, AFOSR funded programs that would ultimately result in the flight pressure suit and the integral flight suit anti-gravity valve. AFOSR-supported research during the 1960s 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 forces involved in high-performance aircraft maneuvering.

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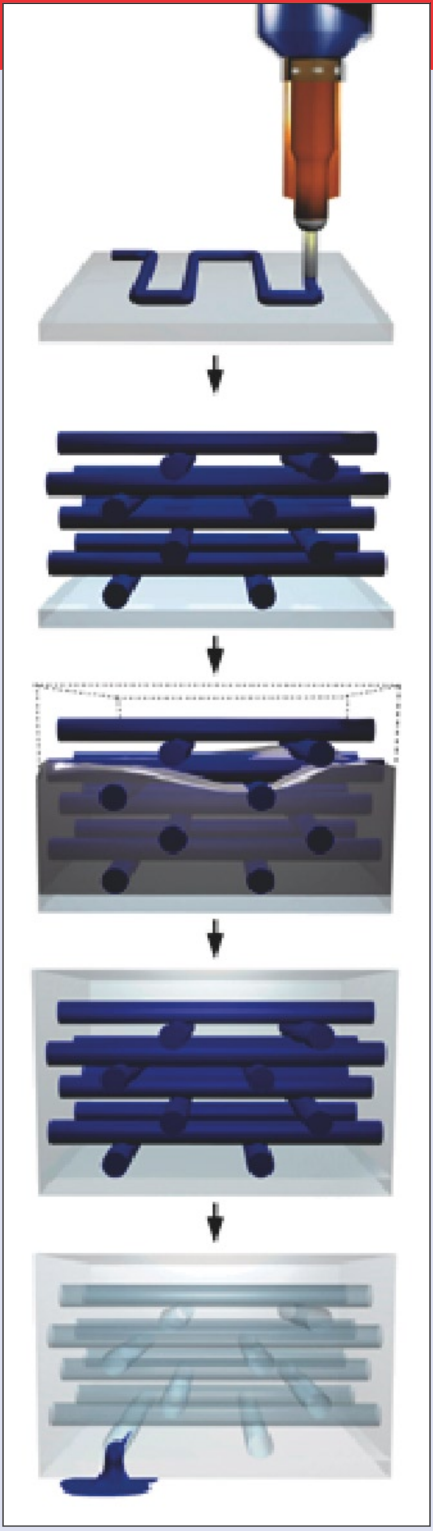
Fabricated Microvascular Networks



Miniature sensors, chemical reactors and computers used for everything from biomedicine to information technology could experience a revolutionary change as a result of Air Force Office of Scientific Research (AFOSR) support.

Dr. Scott White, a Professor of Aerospace Engineering at the University of Illinois at Urbana-Champaign (UIUC) and Willett Faculty Scholar at Beckman Institute for Advanced Sciences and Technology funded by AFOSR, teamed with UIUC scientists to discover a technique for fabricating three-dimensional microvascular networks by using direct-write assembly of organic ink. These miniscule networks could work as compact fluidic factories in sensors, chemical reactors and computers.

Joined by Dr. Jennifer Lewis, a UIUC professor of material science and chemical engineering, and Daniel Therriault, a UIUC graduate student, White and his colleagues were able to produce a pervasive network of interconnected cylindrical channels that can range from 10 to 300 microns in diameter.

With the help of a robotic deposition apparatus and a fugitive organic ink, they created the microvascular network by fabricating a scaffold. Similar to decorating a cake, a computer-controlled robot squeezed ink out of a syringe to build the scaffold layer-by-layer.

"After the layer is generated, the stage is raised and rotated," Lewis noted. "Then another layer is deposited. This process is repeated until the desired structure is produced."

"Once the scaffold has been created," White continued, "it is surrounded with an epoxy resin. After curing, the resin is heated and the liquefied ink is then extracted, leaving behind a network of interlocking tubes and channels."

In the final step, the open network is filled with a photocurable resin. The structure is then selectively masked and polymerized with ultraviolet light to plug selected channels.

Lastly, the uncured resin is drained, leaving the desired pathways in the completed network.

White and team tested their fabrication technique by building square spiral mixing towers within their microvascular networks.

"These three-dimensional towers dramatically improve mixing compared to simple one- and two-dimensional channels," White said. "By forcing the fluids to make right angle turns as they wind their way up the tower, the fluid interface is made to fold on top of itself repeatedly.

"This chaotic advection," he added, "causes the fluids to become well mixed in a short linear distance."

In addition to serving as highly efficient, space-saving mixers in microfluidic devices, White noted that microvascular networks should improve the design of self-healing materials. "Currently, we distribute micro-capsules of healing agent throughout the material," he said. "Where damage occurs locally, the capsules break open and repair the material. With repeated damage in the same location, however, the supply of healing agent may become exhausted."

"By incorporating a microvascular network within the material," White noted, "we could continuously transport an unlimited supply of healing agent, significantly extending the lifetime of the material."

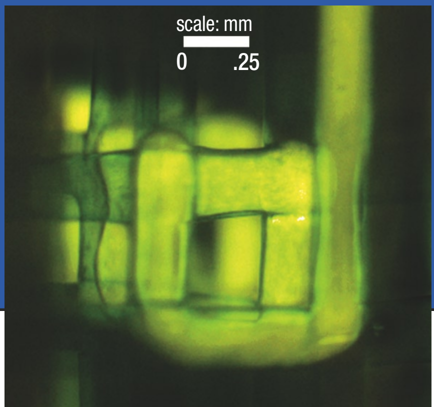
In addition to AFOSR, the National Science Foundation also funded this project.

Dr. B. Les Lee, AFOSR/NA 703-696-8483

FIGURE 1 (above): Schematic of fabrication procedure based on direct-write assembly of a fugitive organic ink followed by matrix infiltration.

PHOTO (center right): Three-dimensional microvascular network embedded in epoxy.

PHOTO (far right): Fluorescent microscope image (showing a top view) of a single square-spiral mixing tower within the microfluidic device after filling with a fluorescent dye. Scale bar, 0.25 mm.



Laser Procedure Helps PFB

TOP PHOTO:
Pre-treatment: A patient suffering from PFB.

BOTTOM PHOTO:
After three treatments spaced one month apart with the 1064 nm Nd:YAG laser, patient sees dramatic results.

Pseudofolliculitis barbae (PFB) is hard to pronounce, but for those forced to shave their curly, coarse facial hair it is even harder to live with. That was until some groundbreaking laser hair removal research, managed by the Air Force Office of Scientific Research (AFOSR) for the DoD funded Medical Free Electron Laser Program (MFEL), led to an important discovery.

Dr. Rox Richard Anderson, associate professor of dermatology at Harvard and an AFOSR-sponsored scientist, invented and developed laser hair removal based on targeting of melanin pigment in the hair follicles using optical pulses, almost 10 years ago. A former colleague, Navy Dr. (Capt.) E. Victor Ross, based in San Diego, Calif., used Anderson's research to propel his recent success in treating PFB.

PFB, according to Anderson, is a disorder that occurs in people with wiry beards and is worsened through repeated, close shaving. Some of the shaved hairs have very sharp ends, which puncture into the skin as the hair grows. This causes inflammation, bleeding, infection, and scarring. It is most common in men of African descent.

Anderson said PFB is especially troublesome to those in the military required to adhere to strict shaving requirements.

"Not shaving at all will cure PFB," Anderson said, "but that is not an option in the military. It also prevents military people from getting a seal while wearing their gas masks; aside from looking a bit haggard."

"These are the same guys prone to keloid scarring," he added, "so PFB often and literally ruins their faces."

Hair removal lasers, Anderson continued, are now the best treatment for PFB. A 10-minute treatment given once a month, he said, inhibits hair growth and PFB, even at power levels which do not cause permanent hair loss.

"Some of the best work has been done by Capt. Vic Ross. He deserves most of the credit," Anderson insisted. "Dr. Ross did a DoD-supported research and clinical training fellowship with me here at Harvard, and his recent work on laser treatment of PFB was done independently."

"He runs a laser treatment center for PFB and other things, and has recognized the potential for small and portable lasers to solve the PFB problem in the military," he added.

The research leading to laser hair removal was supported by the MFEL program and managed by AFOSR's Physics and Electronics program manager, Dr. Howard Schlossberg. "The MFEL program explores the application of pulsed lasers and other optical technologies to combat casualty care and military operational medicine," Schlossberg explained. "The program stimulated the original studies and uses of pulsed lasers in medicine and surgery and has developed more than 30 FDA-approved clinical procedures."

One of those treatment procedures, called selective photo-thermolyis, was developed early on under the MFEL program at Massachusetts General Hospital's Wellman Laboratory for Photo-medicine. "Light pulses are used to selectively affect absorbing targets inside living tissue," Schlossberg noted. "By delivering the light in a brief pulse, the target structures are rapidly and selectively heated, confining thermal injury to the target, while sparing surrounding tissues and cells." This is accomplished by choosing a pulse duration smaller than the thermal relaxation time, or cooling time, of the target.

In hair removal, the selective laser destruction of hair follicles is achieved through the use of wavelengths of light that are well absorbed by melanin, but poorly absorbed by other naturally-occurring chromophores in the skin, such as hemoglobin and water. Schlossberg added that selective photothermolysis has also become the standard of care for the removal of microvascular skin lesions, such as port wine birthmarks, pigmented skin lesions and non-scarring tattoo removal. Schlossberg said in current practice high power lasers, and more recently intense flash lamps, are used with the aim of very long-term or permanent hair loss.

A study at the Wellman Laboratory asked a different question, "What is the minimum dose that will produce a useful effect?" It was learned that at more than an order of magnitude lower power levels than commonly used, hair follicles could be transformed from a growing to a resting state.

"Hair can be kept from growing for periods of about a month," Schlossberg added, "particularly when PFB is concerned." As for PFB, Anderson pointed to a recent study that used a pulsed diode laser to improve the acute and chronic changes of pseudofolliculitis barbae. In the study, all patients exhibited a decrease in the numbers of papules and pustules. Two of the patients who demonstrated more chronic changes, including long-standing hyperpigmentation and fibrotic papules, showed global improvement.

An added benefit of laser treatment was the induction of hair-growth delays in all body areas treated. Each person exhibited a decrease in hair density of greater than 50 percent. The study concluded that it was likely that these patients, in just three treatment sessions, will have achieved a permanent reduction in hair growth.

Dr. Anderson also noted that treatment for PFB in the military would ideally be done with a small, rugged hand-held portable device. A prototype has been developed by Palomar Medical Technologies, a company that licensed Harvard's patents on laser hair removal. Soon, a painless, portable way to prevent PFB might be available to the military.

Dr. Howard Schlossberg, AFOSR/NE 703-696-7549

Basic Research: Giving Wings to Manned Flight

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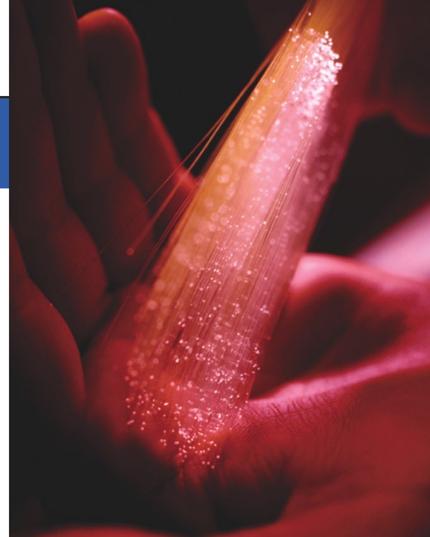
AFOSR-sponsored research in the 1970s and early 1980s looked for ways to increase the strength and fatigue resistance of titanium, aluminum and nickel alloys for airframes. "Superplastic" forming was the outcome, where metals are formed at relatively high temperatures and moderately low strain rates. This process can result in materials that deform over ten times their original dimension, allowing for the production of complex shapes with a minimum of tooling and machining requirements. This led to dramatic cost reductions in the production of F-15E and C-17 aircraft.

With AFOSR funding, the development of a fracture mechanics methodology resulted in the accurate prediction of crack growth rates in aircraft structures. This critical technology is extending aircraft life under the Air Force's aircraft structural integrity program – in particular, the life of the workhorse C-141 Starlifter. Knowledge of crack growth rates is a key determinant in establishing the appropriate inspection intervals for airframes, resulting in preventive maintenance schedules and the best use of maintenance personnel.

Another successful program critical to airframe and engine life extension concerns the development and refinement of non-intrusive diagnostic techniques. AFOSR-funded research from the 1980s applied a new type of laser diagnostics to understand phenomena in high-pressure combustors such as jet engines. This technique – called Photothermal Deflection Spectroscopy – measured concentration and temperature within the engine's flame without affecting the needed data. The other positive aspect of the technique is high signal-to-noise ratios that allow both required measurements – concentration and temperature – to be made with one pump of the laser.



In the 1970s, AFOSR-funded research assisted many technological advances such as glass fiber optics, aerodynamics and rocket propulsion.

One AFOSR initiative, in concert with other federal agencies, resulted in benefits that reached far beyond manned flight. First discovered in 1985 under an AFOSR program, Low Temperature Gallium Arsenide (LT GaAs) is a semi-conducting material widely used in the fabrication of micro-electronic devices. It provides advantages in terms of weight, power consumption, cost, and reliability over more common semiconductor materials and can be produced at temperatures significantly lower than earlier forms of the material. This new semiconductor transitioned to industry very rapidly and is a critical component in MILSTAR satellites, the world's fastest photo detectors, as well as the B-2, F-15, F-16, F-18, and F-22 Phased-Array Radar Systems.

The High-Efficiency Swept Shock Compressor Blade was the result of a 1993 AFOSR program, which not only helped reduce the size of jet engines, but increased efficiency performance. Based on the concept of swept wings, an aspect of supersonic aircraft that reduces performance loss resulting from the shockwave interaction with the wing, AFOSR-funded researchers made rotor blades in axial flow compressors more efficient. These aspirated and swept shocked compressor fan blades improved compressor efficiency by almost 90 percent and resulted in engines with fewer stages and higher thrust-to-weight ratios. The increase in performance meant more powerful engines with increased range due to reduced fuel consumption.

The revolutionary innovations in manned flight today are the result of AFOSR's work many years ago. In keeping with that tradition, AFOSR is currently working hard on the innovations that will become reality many years hence.

Ultimately, whatever form manned flight will take in the future, AFOSR will help plot the revolutionary flight path to get there.

Dr. Robert White, AFOSR/PI 703-588-0665

Research Highlights

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AFOSR would like to thank Drs. Scott White, Les Lee, Howard Schlossberg, Rox Richard Anderson, Victor Ross (Capt.), and Robert White for their assistance in making this issue possible.

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

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