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2014 Annual Report of the Graduate School of Engineering and Management, Air Force Institute of Technology

Office of Research and Sponsored Programs, Graduate School of Engineering and Management, AFIT

AIR FORCE INSTITUTE OF TECHNOLOGY

GRADUATE SCHOOL OF ENGINEERING AND MANAGEMENT

2014 ANNUAL REPORT

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This Annual Report is published each year by AFIT's Office of Research and Sponsored Programs at Wright-Patterson Air Force Base, Ohio. It shares information about the activities of the Graduate School of Engineering and Management at AFIT with the Air Force, Department of Defense, and wider public. All images are Air Force, NASA, or AFIT owned or used with permission unless otherwise identified. The DOD, other Federal Government, and non-Government agencies supported the research reported herein but have not reviewed nor endorsed the contents of this publication.

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MESSAGE from the Dean

On November 10, 1919, Col Thurman Bane received authorization to begin instruction at the Air School of Application. The following year, the first class of nine students graduated from the newly-named Air Services Engineering School. Ninety-five years later, the Air Force Institute of Technology's (AFIT) Graduate School of Engineering and Management has awarded more than 18,000 master's and 700 doctorate degrees. The appeal for AFIT's distinct educational opportunities continues to be wide-spread attracting the highest quality of faculty and students.

We remain focused on providing exceptional defense-focused, research-based graduate education that is responsive to our customers. Research programs at AFIT are an integral component of our mission, and provide valuable technical and management experiences that enhance our graduates' performance throughout their careers. To maximize value, AFIT's research efforts are aligned with strategic priorities identified in guidance such as *America's Air Force: A Call to the Future* (2014), the *United States Air Force Chief Scientist's report Technology Horizons*, *A Vision for Air Force Science and Technology During 2010-2030*, and the *Air Force Science & Technology Strategy 2014*.

This year's report highlights the recent research achievements of our faculty and students, and features the outstanding work of our researchers in the Autonomy and Navigation Technology (ANT) Center, previously the Advanced Navigation Technology Center. Under its new name, the ANT Center's current research in cooperative and autonomous systems investigates auto-routing and optimal path planning, multi-agent cooperative control, mobile adaptive networks, robust navigation solutions, and reduced operator manning workload.

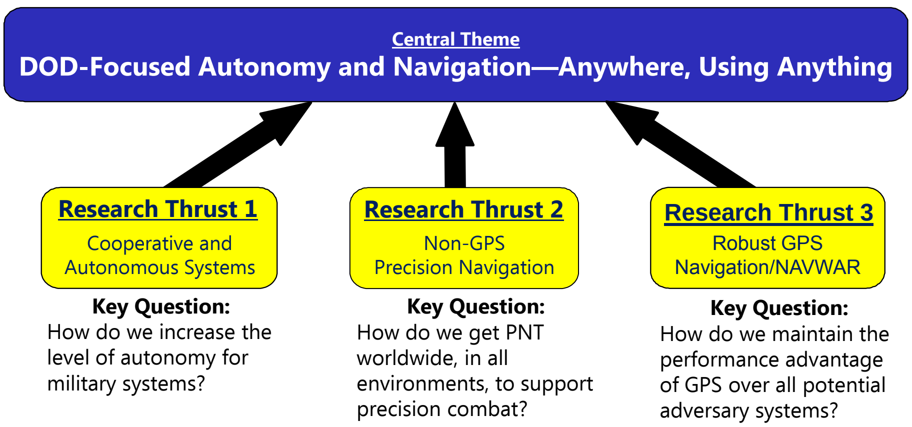
As we reflect on 2014 achievements with pride, the faculty, staff, and I are working hard to align our core missions of education, research, and consultation/service in exploring new innovation in delivering our graduate education programs; leveraging our research pursuits to provide relevant and timely contributions to solve the pressing problems of today; and reaching out beyond the Air Force fence to address the needs of the society within which we live. We will continuously strive toward our vision of excellence in defense-focused, research-based engineering to better serve our students, the United States Air Force, and our nation.

With best regards,
Adedeji B. Badiru, Ph.D., PE
Dean, Graduate School of Engineering and Management
Air Force Institute of Technology

CENTER SPOTLIGHT
Autonomy and Navigation Technology Center

The Autonomy and Navigation Technology (ANT) Center is a forward-looking research center tackling autonomy and navigation-related technology problems that are of interest to the Air Force and the Department of Defense (DOD) since its establishment in 2006. The DOD has increasingly recognized the need for both autonomy and the ability to have reliable navigation in any environment. The Center's goal is to develop autonomy and navigation technology that ensures we can operate anywhere, anytime, using anything.

In recognition of the growing emphasis on autonomy-related research, in May 2014 the Center changed its name from the "Advanced Navigation Technology Center" to the "Autonomy and Navigation Technology Center." This new name more accurately represents the three main research thrusts of the center, which have remained unchanged.



ANT Center Impact:

- Performs significant research for more than 10 organizations including Air Force Research Laboratory (AFRL), Defense Advanced Research Projects Agency (DARPA), the Air Force Office of Scientific Research (AFOSR), and the 746th Test Squadron
- Led the world's largest navigation system data collection (over 60 sensors on pedestrian, van, and aircraft) in support of the DARPA All-Source Position and Navigation (ASPN) Program
- Designated a "Pioneer in Precision Navigation" by the Air Force Association
- Significant contributor to the vision navigation field—over 50 MS theses and PhD dissertations on this topic alone

An increase in the number of autonomous systems projects over the past few years is due in large part to the three course Unmanned Airborne Systems (UAS) design sequence, in which students design, build, and flight test a UAS in order to solve a problem of interest to the DOD.

Since its formation in 2006, the Center has distinguished itself with high-quality, relevant, hands-on research and has educated hundreds of students. Under its new name, the ANT Center will continue to make significant contributions to the autonomy and navigation research community in the years to come.

For more information go to http://www.afit.edu/ANT/ and to view featured ANT Center research videos, go to: https://www.youtube.com/user/ANTcenter/featured.

Automated Aerial Refueling: Precise Relative Navigation from Stereo Vision

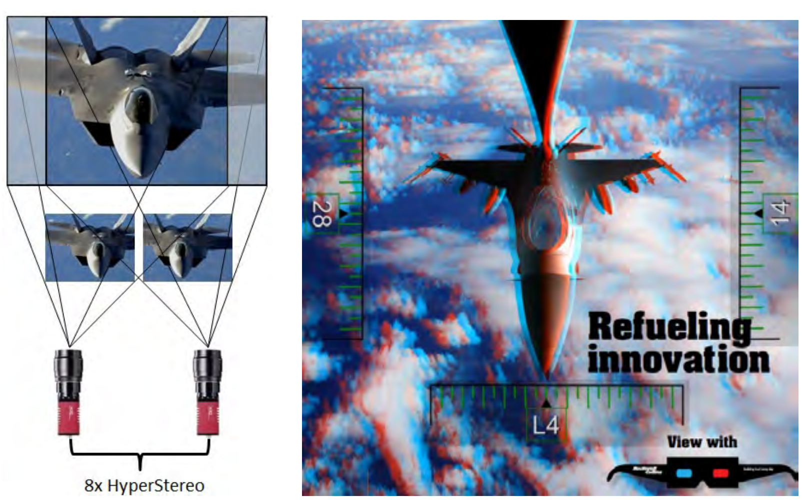
Maj Brian Woolley • Brian.Woolley@afit.edu • 937-255-3636 x4618

Working in coordination with the AFRL Aerospace Systems Directorate, the ANT Center is leveraging 3D sensing capability, provided by stereoscopic camera technology, to enable automated refueling of unmanned aerial systems (UAS) and remotely piloted aircraft (RPA). Aerial refueling is a key enabler of the Air Force's global mobility mission that is currently not available to UAS and RPAs, because they lack an onboard pilot capable of safely maintaining an appropriate refueling position. Interestingly, the upcoming KC-46 tanker has moved the boom operator to the front of the plane where they fly the boom via a 3D display driven by a stereoscopic camera system mounted at the rear of the tanker. ANT Center researchers are confident this organic vision system in the Air Force's new tanker will be useful for automated UAS and RPA refueling.

The aim of the current research draws on established technologies in the fields of computer vision and navigation to generate precise relative positioning information about the receiving (i.e. trailing) aircraft in real-time. While previous research with monocular camera systems have been shown to provide positioning information, a stereoscopic system provides inherent depth cues that enhance positioning accuracy. Additionally, the resulting system will also provide a day/night, all-weather capability that is not based on differential GPS signaling and does not require specialized sensors embedded in the trailing aircraft.

In the future, such positioning information may allow the tanker to provide a UAS or RPA with a delta between its current position and a specified station-keeping goal. The simplicity of this approach is that the receiving aircraft's goal position remains fixed relative to the tanker—even during banked turns. A key element of this approach is that the tanker is not required to know how to fly the receiving aircraft directly. Rather, the internal flight control system for the UAS or RPA takes the position deltas provided by the tanker and is free to respond in the way that is most appropriate for that individual aircraft.

The ultimate objective of this research is to leverage organic systems in the KC-46 refueler to deliver precision-relative position information in real-time as an enabler for an automated flight control system to position itself into a stable refueling position.



Stereoscopic imaging provides the depth cues necessary for refueling operations.

UAV Vision-Aided Navigation

Dr. John Raquet • John.Raquet@afit.edu • 937-255-3636 x4580

In partnership with AFRL's Sensors Directorate, the ANT Center is bringing needed capability to the warfighter by developing technology to enable Unmanned Aerial Vehicle (UAV) operations in a GPS-denied Anti-Access Area-Denial (A2AD) environment.

The UAV Vision-Aided Navigation (UVAN) project is designed to demonstrate the capabilities of image-aided navigation solutions in realistic scenarios. The ANT Center and AFRL have developed a pod-based vision navigation system which is designed to operate when GPS is not available. The system compares images from a camera with previously collected satellite imagery and integrates this information with an inertial navigation system in order to determine a real-time navigation solution without the use of GPS. This system has been successfully flight tested, and plans are in place to continue to develop the system and test it in a variety of conditions.

UVAN pod mounted to right wing of Cessna 172

Space Jam

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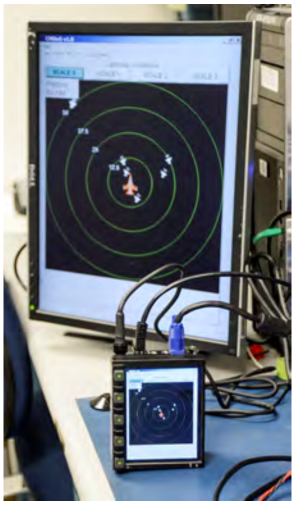
Recent AFIT graduate, Capt David Levene, designed and built a system that is able to emulate jamming in an operational aircraft in a realistic way.

A form-fit replacement for a standard GPS antenna electronics box was built, which was able to inject a jamming signal into the aircraft that was representative of what would be present in an open-air jamming environment. Since no open-air jamming was involved, the "Space Jam" can be operated in just about any environment, making it ideal for aircrew training and tactics development.

Capt Levene was the recipient of the prestigious Chancellor's Award, which is given to the top master's research thesis in the AFIT Graduate School of Engineering and Management. Capt Levene worked with researchers from the ANT Center, AFRL, and the USAF Test Pilot School. The system was flight tested as part of the AFIT/Test Pilot School program.



Space Jam Controller Display

Global Navigation Satellite System

Dr. Sanjeev Gunawardena • Sanjeev.Gunawardena@afit.edu • 937-255-3636 x4659

Dr. Sanjeev Gunawardena, ANT Center research assistant professor, and researchers from the AFRL Sensors Directorate, are investigating multi-Global Navigation Satellite System (GNSS) flexible receiver architectures, next-generation implementation platforms, advanced GNSS signal monitoring and authentication techniques, and technologies for improving GNSS robustness against interference.

The US Global Positioning System (GPS) remains the key provider of robust position navigation and timing (PNT) capabilities for today's warfighter, and the Russian GLONASS system is the only other fully-operational GNSS. However, the past several years have seen the deployment of several global, as well as regional, satellite navigation systems. These include Europe's Galileo, China's BeiDou System, and the Japanese Quasi-Zenith Satellite System. These modern GNSS signals utilize different types of modulations and are spread out over a wider radio frequency spectrum. Hence, PNT robustness and availability can be significantly improved when using all GNSS signals. However, techniques must be developed to guarantee a similar level of trust for non-GPS signals.

Research Engineer Mark Carroll performs data collection using a multi-element antenna.

The GNSS research team is also investigating technologies to significantly reduce the size, weight, power, and cost of multi-element beamforming receiver implementations. Currently these types of systems are only used in large platforms. The team hopes to develop a novel architecture that will allow such systems to be deployed in platforms such as small UAVs and land vehicles.

All Source Positioning and Navigation

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The ANT Center demonstrated their world-class ability to collect high-quality data from a wide variety of navigation sensors as they led what could be called the world's largest navigation system data collection. In support of DARPA's ASPN Program, the Center teamed with Ohio University and The Ohio State University to collect data from over 60 different navigation sensors on a variety of platforms, including pedestrian navigation, ground vehicles, and aircraft. Some of the sensors that were used included several grades of inertial navigation systems, ranging radios, cameras, magnetometers, lidars, barometric altimeters, odometers, tilt sensors, laser altimeters, radars, and GPS receivers. This data was then provided to a number of industry performers on the ASPN Program in order to test their navigation algorithms.

ANT Center Navigation Sensor Rack being mounted on Ohio University's Test Van for ASPN Data Collection.

RESEARCH Highlights

USAF Aircraft Corrosion Control: Isocyanate Sampling Research

Lt Col Dirk Yamamoto • Dirk.Yamamoto@afit.edu • 937-255-3636 x4511

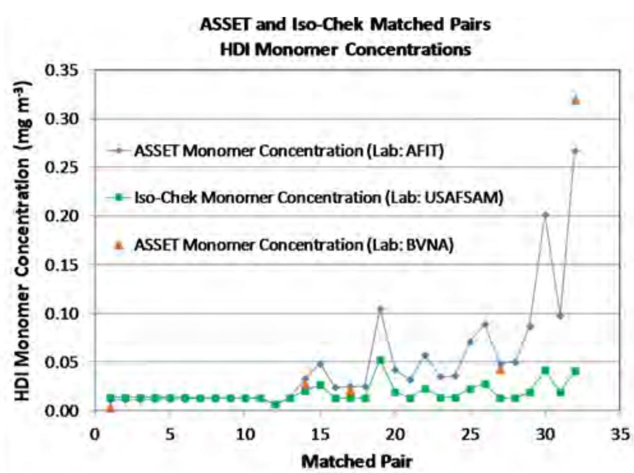
Isocyanate-based polyurethane coatings are used on United States Air Force (USAF) fighter, bomber, and cargo aircraft because of their abrasion resistance, chemical and impact resistance, flexibility, and weatherability. However, such coatings are typically some of the most hazardous chemical exposures at an Air Force base, thus warranting extensive air sampling to determine exposures and resulting risk.

Assistant Professor Lt Col Dirk Yamamoto and graduate student, Capt Tiffany Heline, in the Department of Systems Engineering and Management, evaluated the new Sigma-Aldrich Supelco ASSET™ EZ-NCO Dry Sampler (referred to as 'ASSET™'), in comparison with the ISO-CHEK® method, during aircraft refinishing operations. ISO-CHEK® is the current method for air sampling of isocyanates. The sampler requires chemical desorption of samples in the field, compliance with Department of Transportation rules for shipping hazardous materials, and frequent swap-out of collection media during the workshift. Burdensome sampling technology leads to decreased sampling, leaving AF bases unable to adequately assess health risk and causes potential non-compliance with OSHA regulations.

Capt Heline collected employee breathing zone air samples using the ASSET™ sampler (n = 56) and ISO-CHEK® (n = 54) protocols during C-5 cargo aircraft interior refurbishment, using high volume/low pressure spray guns and high-gloss polyurethane paint. Samples collected using the ASSET™ sampler were analyzed via an AFIT-developed methodology relying on High Performance Liquid Chromatography. Analysis was performed in collaboration with the USAF School of Aerospace Medicine.

Results indicated that the ASSET™ sampler collected significantly higher levels of 1,6-hexamethylene diisocyanate monomers (mean difference=0.0029 mg/m3, p=0.002). A plot of matched-pair concentrations indicated the mean difference in monomer results is proportional to measured concentration. A cost comparison between the two methods, using estimates for sampling media, analytical, and equipment costs, indicated that the ASSET™ sampler provided an estimated 52% cost savings over the ISO-CHEK® method. Although further studies are likely warranted, this preliminary research indicates that the ASSET™ sampler provides a cost-effective, easy-to-use sampling solution for the USAF.

Air sampling during spray painting of C-5 cargo aircraft interior to compare the performance of two sampling methods.



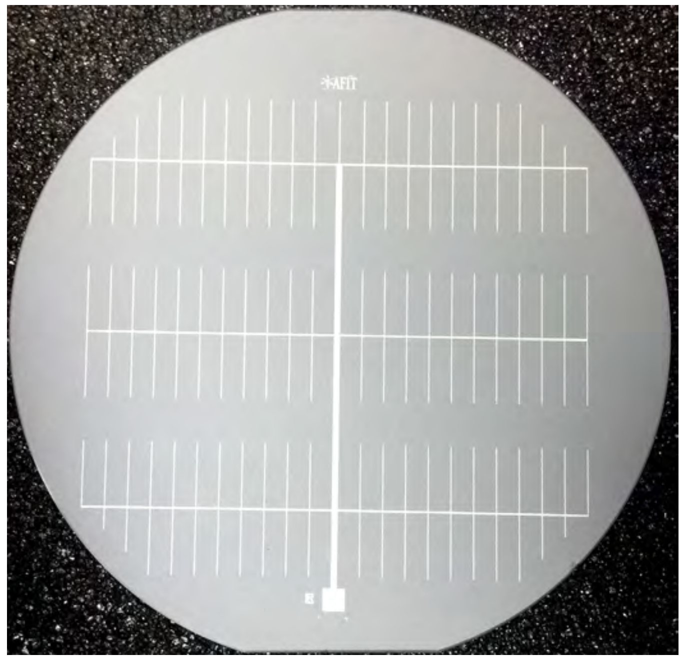
Plot of ASSET™ and ISO-CHEK® monomer results indicates the mean difference in monomer results is proportional to measured concentration.

AFIT Begins Solar Cell Fabrication at Two Levels

Dr. Ronald Coutu • Ronald.Coutu@afit.edu • 937-255-3636 x7230

From pocket calculators to GPS satellites, photovoltaic technology provides power to a wide range of electronics. However, despite over 50 years of focused research, silicon solar cells only turn roughly 25% of sunlight into usable power. Advanced technology that stacks different materials can reach efficiencies over 44%, but the complex structure of these multi-junction cells is cost-prohibitive for mass production. The low efficiency rating of single-layer silicon solar cells is caused by light reflection and heat. Using existing manufacturing techniques, graduate student 1Lt Robert LaFleur in the Department of Electrical and Computer Engineering, addressed these limiting factors through a novel hybrid multi-junction (HMJ) architecture.

In order to improve light trapping, two single-layer cells are stacked on top of one another with an air gap in between them. The light in the top cell that doesn't get absorbed and turned into electricity is allowed to propagate into the bottom cell after passing through a specifically-designed grating pattern. This grating, like mini-blinds on a window, provides varying degrees of light intensity on the bottom cell through interacting light waves known as interference patterns. Reflection is significantly reduced by placing the bottom cell's front contacts completely within the resulting "shadow bands." Light that enters the bottom cell can then be absorbed and converted into electricity. Additionally, any light that is reflected away from the bottom cell has another chance for absorption as it passes back through the top cell. The air gap, in addition to enabling interference pattern formation, also provides thermal isolation between the cells. Since efficiency drops as solar cells get hot, the bottom cell maintains a higher efficiency by remaining at a cooler temperature. Heat is also generated when photons with too much energy are absorbed by silicon. Designing the grating pattern to trap these photons in the top cell allows photons with an optimal amount of energy to generate photocurrent in the bottom cell without excessive heat.



Front view of solar cell

Future HMJ designs will seek to exploit "photon filtering" by altering the material of the top cell to take advantage of the higher energy photons. The HMJ silicon architectures fabricated at AFIT have shown a 20% increase in photocurrent versus single-layer silicon cells. Additional developments are currently underway to improve the response of the HMJ design and include optimized front contact spacing and wafer orientation. Refined HMJ architectures will provide more power and require less surface area without increasing fabrication costs, making mass production feasible and the impact of this research substantial.

Nanomaterial and Nanotechnology Research for Bio-Defeat Weapon Development

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Effective and quick neutralization of *Bacillus anthracis* spores as biological weapons is of paramount importance to antibioterrorism, food safety, environmental protection, and the medical device industry. Thus, a deeper understanding of the mechanisms of spore resistance and inactivation is highly desired for developing new strategies or improving the known methods for spore destruction. Conventional bio-defeat strategies target the damage to the essential molecules of spores such as DNA, RNA, and enzymes through chemical or biochemical reactions, which may often take a long time and are susceptible to changes in environmental conditions. Dr. Alex Li and researchers within the Department of Engineering Physics have focused on the development of a thermal flash method that produces large thermo-mechanical stresses in the spore in a short period of time. This method tears the essential molecules, which are embedded and protected by the structure of spores.

This novel approach, which is less sensitive to environmental changes caused by detonation product gases and other corrosive bio-defeat agents, can be potentially used to advance the bio-defeat weapon designs. Using atomic force microscopy and other microscopic techniques, researchers observed significant changes in surface morphology and structure of the spores on the nanometer scale (see Figure 1), which can be correlated to different thermal treatments. They showed the importance of thermal stresses and heat transfer to spore inactivation by very rapid dry heating.

Dr. Li's research was featured in a leading microbiology journal, *Applied and Environmental Microbiology*, and selected as the best American Society for Microbiology journal paper in *Microbe Magazine* March 2014 issue.

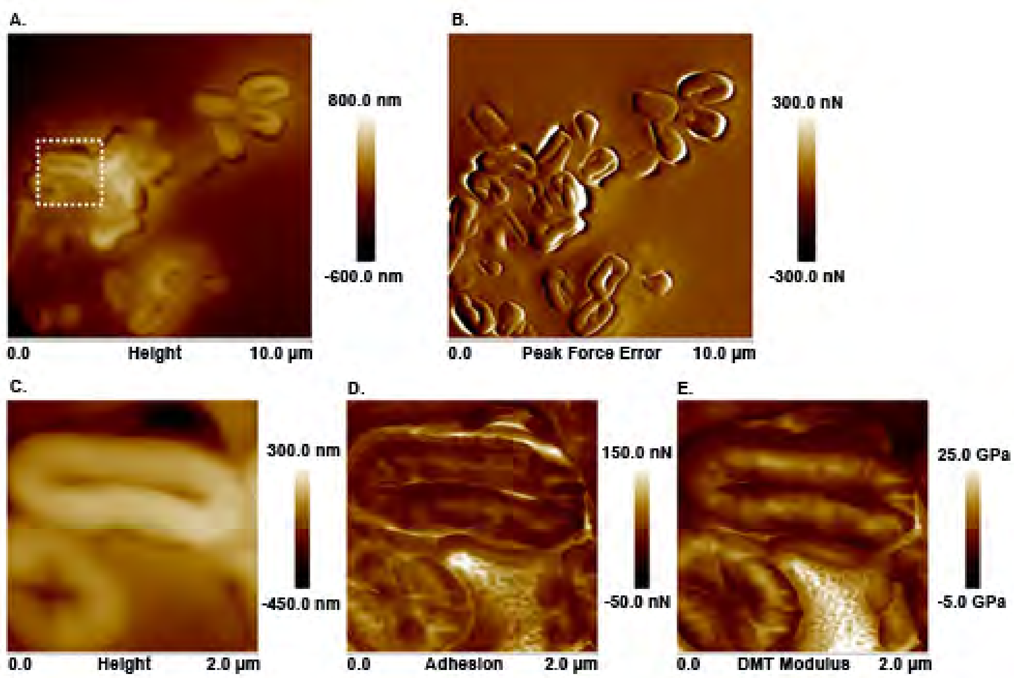

Figure 1. Atomic Force Microscopy (AFM) images showing thermal flash damage to structures and properties of *Bacillus anthracis* spores at 300°C for 100 seconds. (A) AFM height image; (B) AFM peak force image; (C, D, and E) high-resolution AFM images of the height, adhesion force, and modulus of two spores highlighted by the dotted line in panel A.

Understanding the Physics of Nuclear Weapon Detonations

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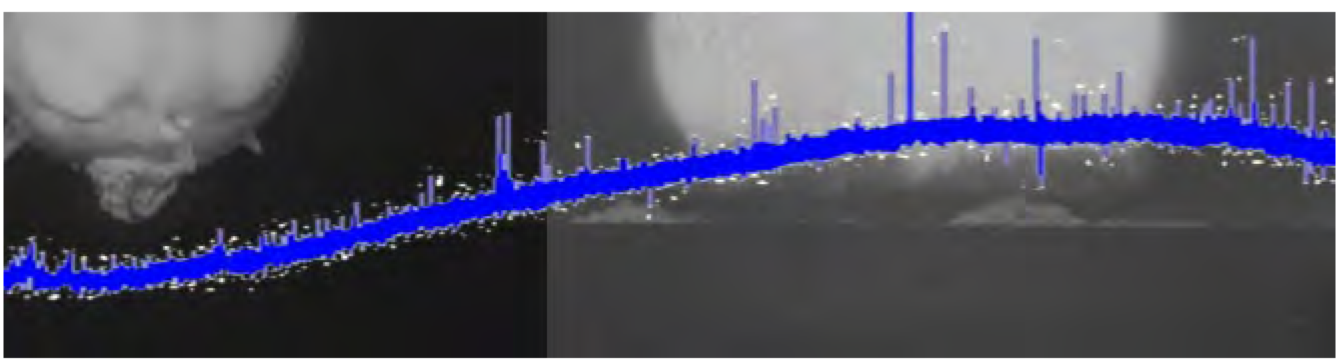
The detonation of a nuclear weapon produces a unique optical signature which can be used to determine key parameters of the weapon to include the device yield. The yield is a critical parameter necessary to estimate a nation's level of sophistication with respect to weapon design. However, this signature can be altered so that the yield appears much larger based on the standard empirical relationships, by simply increasing the total mass surrounding it. This change could lead strategic planners to grossly overestimate a nation's current state of nuclear weapons development.

Maj Michael Dexter, doctoral student in the Department of Engineering Physics, in cooperation with the Defense Threat Reduction Agency and the Lawrence Livermore National Laboratory, is studying the fundamental physical process responsible for nuclear weapon optical output in order to develop a new methodology for determining device yield without any prior knowledge of weapon design. Research to date suggests that the shift in the optical signature is likely the result of the interaction of light with the dense plasma produced through the extraordinary heating and shock compression of the mass immediately surrounding the device.

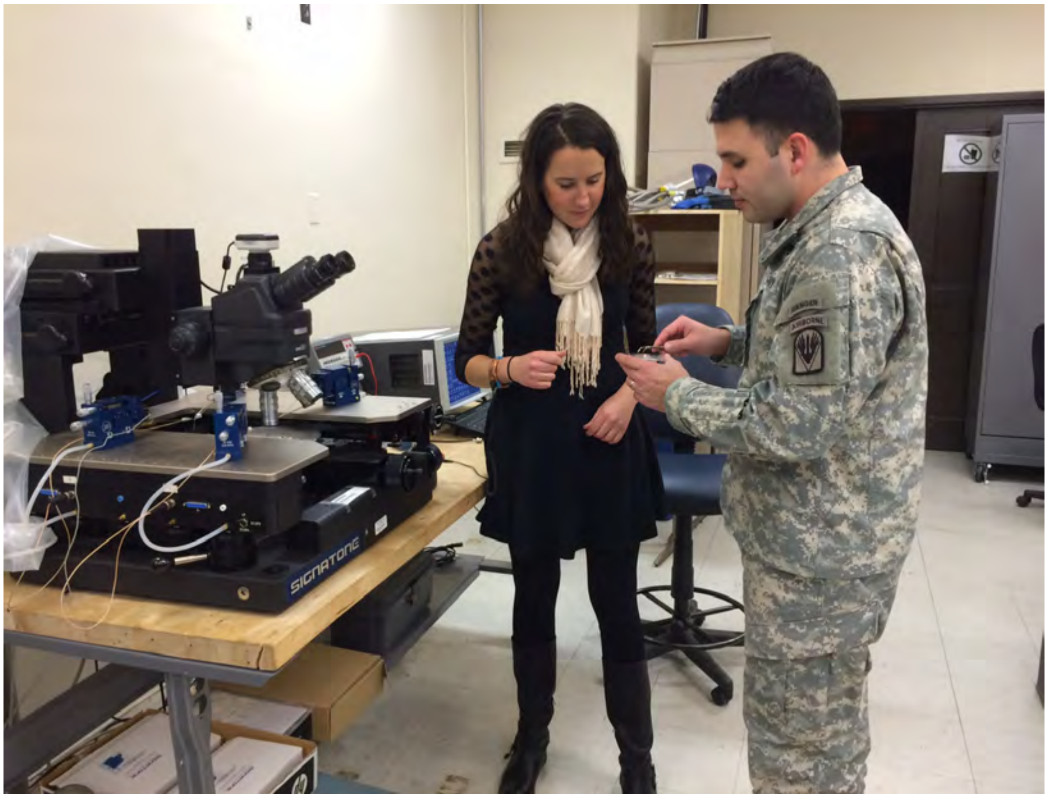
To determine the impact of this ultra-dense plasma on the optical output, Maj Dexter is utilizing a one-dimensional radiation hydrodynamics code to perform a parameter study in which the opacity, equation of state, and ratio of specific heats of the system are varied to produce the visible optical output for each parameter set. This optical output will then be compared to historic data extracted from recently-digitized nuclear test films for a variety of detonations with known mass configurations. Once the correct parameter set is determined, this data will be used to simulate the frequency dependent output expected from a device of various mass configurations. This should provide new empirical relationships to determine atmospheric nuclear weapon yields.



Variation of optical output of a nuclear detonation from time of first light to approximately 3 seconds.

Two-dimensional Electronics for Space Applications

Dr. John McClory • John.McClory@afit.edu • 937-255-3636 x7308



MAJ Brian Barnett and post-doctoral researcher Dr. Ashley Francis confer on methods for analyzing irradiated 2-D electronic structures using AFIT's probe station and semiconductor analyzer.

AFIT faculty and students in the Department of Engineering Physics are collaborating with the Naval Research Laboratory and AFRL to investigate one- and two-dimensional materials for electronic applications in the space environment.

Carbon-based electronic materials, such as graphene and carbon nanotubes, have tremendous potential in the electronics industry for applications ranging from field-effect transistors and sensors to radio frequency communications. These carbon-based materials have excellent thermal conductivity and current-carrying capabilities compared to silicon, which is the material used in the majority of today's electronics. Because of their low density, low atomic number, and small cross section, graphene and carbon nanotube-based devices potentially have high resistance to radiation damage compared to silicon-based devices, making them especially attractive for the space radiation environment.

One of the challenges facing carbon-based devices is their extreme sensitivity to the environment, and the effects of the underlying substrate and surrounding materials, which have a significant impact on device performance. In this same line of research, another two-dimensional material, boron nitride, is also gaining much attention as a passivating dielectric, which can be used to isolate graphene and carbon nanotube channel material from the environment, as well as supporting substrate material for graphene-based devices.

Past research conducted by AFIT focused on the effects of electron, proton, and x-ray irradiation on aggressively-scaled carbon nanotube and graphene transistors. Electrical and optical characterization of the devices following both ionizing and non-ionizing radiation have shown that carbon nanotubes and graphene have an extremely high tolerance to both ionizing and non-ionizing radiation, and that the device response is dominated by radiation effects in the surrounding substrate and oxide materials. In the current research, AFIT graduate students are investigating the electrical and optical properties of boron nitride.

Trusted Avionics Research

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The increased number of embedded computer systems and their interconnectivity to wired and wireless networks has produced a growing and focused cybersecurity research area in securing aircraft avionics from malicious intrusion. Avionics include communications, navigation, display and management of multiple systems, and hundreds of other electronic systems custom fitted in aircraft to perform individual functions. These avionics systems do not employ the same operating systems that standard desktop computers use; instead, they tend to use embedded microprocessors with custom software or field programmable gate arrays to control operations.

AFIT cyber operations graduate student, Ms. Gabrielle Vanderburgh, is working with AFRL's Sensors Directorate to develop methodologies for conducting security assessment testing of avionics equipment commonly found in modern commercial aircraft.

The vulnerability of the avionics systems exists at or near this physical hardware level. Anti-virus and anti-malware software operate on top of operating systems and do not have visibility of the low-level hardware operations. Root kits and other low-level exploits can easily remain undetected. Another security concern is with the use of commercial off-the-shelf devices within avionics systems which have the potential for an adversary to threaten the safe operation of aircraft.

Since commercial vendors do not typically provide proprietary information necessary to facilitate a security analysis, Ms. Vanderburgh is developing a black box testing methodology for avionics, which assumes that the tester has limited knowledge of the internal functionality of a device to help researchers conduct avionics security assessments. The developed methodology will incorporate elements across multiple domains including computer and electrical engineering, computer science, reverse engineering, and automated fuzz testing of random data inputs.

In conjunction with graduate student research in the trusted avionics realm, the Center for Cyberspace Research is working with AFIT's School of Systems and Logistics and the Air Force Life Cycle Management Center to define requirements for updating or creating new training modules for the acquisition community. The training modules are intended to raise the overall cyber literacy of the aircraft communities and are intended to be a certificate-track, multi-tiered curriculum covering material from basic cyber security concepts to specific, job-oriented information and case studies.

Active Research in Passive Radar Imaging

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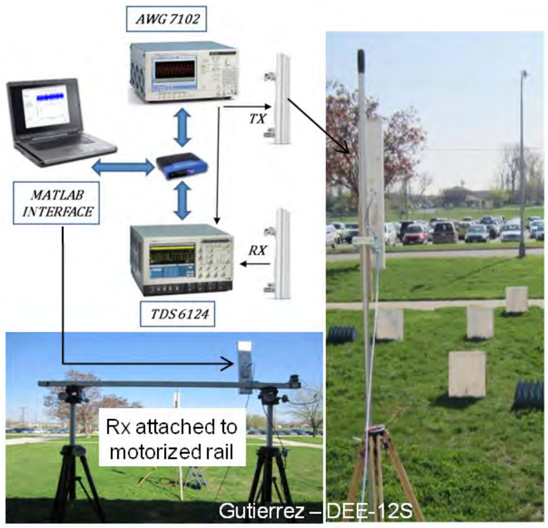
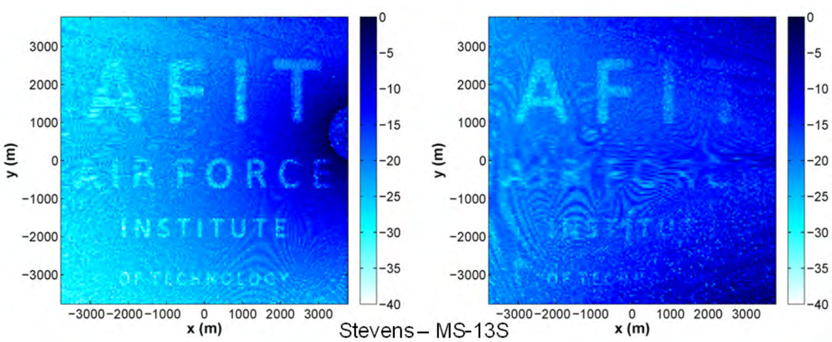
AFIT's Radar Instrumentation Laboratory (RAIL) is leading the way to advance radar imaging technology using signals of opportunity. As worldwide use of broadcast and mobile communication increases, spectral bands traditionally used for radar sensing are being redirected to provide larger bandwidths to the telecom market. Dr. Julie Jackson, Associate Professor in the Department of Electrical and Computer Engineering, and RAIL team researchers are working with AFRL's Sensors Directorate to utilize communications signals already present in the environment to perform low-power consumption surveillance and form radar images.

Receive-only sensing faces difficult and unique challenges in signal timing, signal dynamic range, waveform properties, and signal processing. Waveforms designed for communication are not necessarily optimized for radar applications. AFIT has investigated a variety of signal standards, including 802.16 WiMAX and 4G LTE, and characterized waveform properties for radar imaging applications. AFIT students working with Dr. Jackson have implemented signal simulation and radar imaging experiments in RAIL. They developed and tested new signal processing strategies that utilize knowledge of features embedded in the digital communication waveforms to form high-quality radar images. The students have also defined metrics for choosing the best emitters to use for receive-only imaging in a dense radio frequency (RF) environment.

The RAIL team is at the forefront of radar ground imaging research using signals of opportunity. Future work will extend signal models and testing to incorporate variability seen in real-world RF emissions.



AFIT's RAIL experimental radar system transmits digital communication waveforms, while a receiver independently collects data. New signal processing techniques reduce image background clutter for improved target detection.



AFIT's RAIL emitter selection tool demonstrates for a simulated scene that utilization of one HDTV and two LTE transmitters (left) results in better image quality than one WiMAX and three LTE transmitters (right) due to waveform properties and emitter locations relative to the receiver.

Hypersonic Thermal Protection Coupled Ablation-Radiation Simulations

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In partnership with the University of Queensland, Australia, AFIT is leveraging expertise in the areas of hypersonic ground testing and computational fluid dynamics to improve the prediction and analysis of hypersonic ablating flow fields and investigate radiative flow intensities.

Hypersonic systems are a key technology area that would enable the Air Force to operate in anti-access/area denial environments. Mission areas of interest include Penetrating Persistent Long-Range Strike, High-Speed Penetrating Cruise Missile, and Reusable Airbreathing Access-to-Space Launch. Development of hypersonic systems encompasses a multitude of scientific disciplines, but the design of thermal protection systems (TPS) is one of the most critical investment areas.

TPS are subjected to severe thermal and mechanical loads when exposed to hypersonic re-entry environments and must be designed to prevent excessive heat from damaging the vehicle. The materials used for TPS interact with the hot gas through various processes, with an important process being ablation. Ablation occurs when the TPS material converts to liquid or gas, which usually reduces the temperature of the vehicle. Surface chemical reactions play a prominent role in determining ablation and energy transfer rates. The correct understanding and accurate modeling of the ablation phenomena plays an integral part in the design of TPS for re-entry vehicles and/or hypersonic weapons. Hot gases tend to radiate energy away from the vehicle. The radiation that is emitted away from a re-entry vehicle is of paramount interest to design engineers.

The experiments were performed in the X-2 shock expansion tunnel at the University of Queensland, which is used to test subscale models at realistic re-entry flight conditions. The model used in the experiments was made of graphite (i.e. pure carbon). In addition, the graphite model is pre-heated to very hot temperatures from around 2000 to 3000 K (3140 F – 4940 F) to also simulate a realistic re-entry environment. Ultraviolet spectrometry was used to measure Cyanogen (CN) radiation intensities in the shock layer (see Figure 1 for example data output).

The computational portion of this work attempts to improve current ablation models that rely on kinetics-based chemical reactions, which are more representative of physical processes. The research completed at AFIT has been shown to accurately predict some of the measured spectra and can be matched where peak radiative intensities are located in the shock layer.

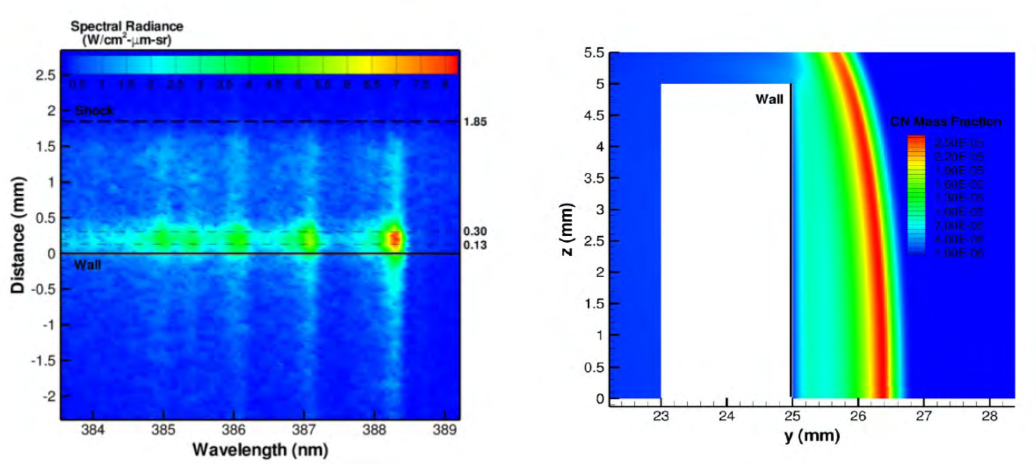
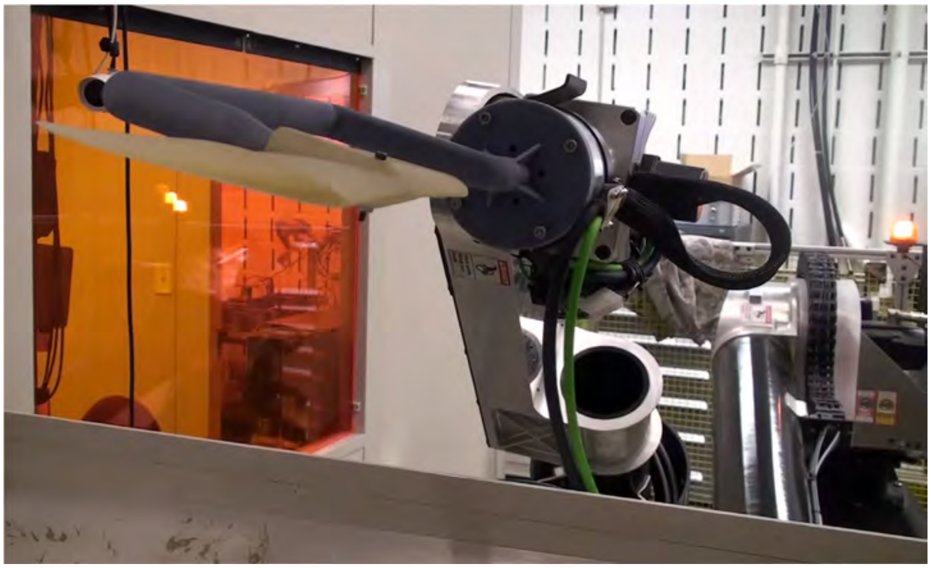


Figure 1. Chart on the left shows UV Spectrometer results of CN radiation intensities. Peak radiation correlates to CN mass fraction (right).

Flight Test in the AFIT Low Speed Wind Tunnel

Dr. Mark Reeder • Mark.Reeder@afit.edu • 937-255-3636 x4530

In support of the AFRL Munitions Directorate's "flex weapon" concept, Dr. Mark Reeder, Professor in the Department of Aeronautics and Astronautics, and graduate students have been conducting tests using a new robotic arm installed in AFIT's Low Speed Wind Tunnel facility. The six degree-of-freedom (DOF) Motion Test Apparatus (MTA) will enable a broad range of aerodynamics experiments, encompassing "flex weapon" development, store separation, small unmanned vehicle dynamics in the presence of wind gusts, ground effect characterization, and many other possibilities.



6-DOF MTA

The "flex weapon" concept is a munition which can be assembled by users in the field from different parts, based on the desired mission. This concept poses significant challenges for designers because aerodynamic data would be required for hundreds of physical configurations, all of which will require different control systems. The MTA in the wind tunnel offers a significant capability in the testing and real-time control of such weapons in a real aerodynamic environment.

Dr. Reeder's research is aimed at decreasing the burden of testing through intelligent application of design of experiments (DOE) and advanced statistics. Simulation, stability, controls, performance estimation and load engineers, as well as others, require a wind tunnel-generated map of aerodynamic loads data to perform their respective analyses.

The data are typically gathered as functions of angle of attack, angle of sideslip, roll angle, Mach number, fin deflection, and possibly other variables. This mapping may be performed in its entirety for a given outer mold line (OML) aerodynamic shape; however, the "flex weapon" concept multiplies these tests by a conceivably large number of configurations with different OMLs. Although each change to OML will affect aerodynamic loads to some degree, completely mapping the load data for every configuration is prohibitively expensive. An alternative method is sought where DOE concepts are used in a simulated test case to evaluate the differing loads and use metrics to determine the added value of completing a map for a given OML vs. modifying existing data to meet user needs.

The 6-DOF MTA will be used to develop this map for a given model. The generated maps will then be used to schedule gains and control behaviors. The actual wind tunnel models will have servo-controlled surfaces, which have control systems in the loop. The resulting controllability of the models will then be assessed to determine the effectiveness of the surrogate mapping techniques developed at the University of Florida's Research and Engineering Education Facility (REEF) Aerodynamic Characterization Facility. Future work is envisioned to focus on closed-loop control of small unmanned aircraft systems for autonomous missions, flow control, and precision weapons release.

Helping Helicopter Aircrew with Lower Back Pain

Dr. Christine Schubert Kabban • Christine.Schubert@afit.edu • 937-255-3636 x4549

Lower back pain in helicopter crew members has been reported at between 51-92%, much higher than the reported 12-33% from the general population. Aircraft ergonomics and vibration exposure, among other potential sources, may attribute to the increased prevalence of this pain.

Dr. Christine Schubert Kabban, from the Department of Mathematics, and Statistics and Col Anthony Tvarynas, from the 711th Human Performance Wing, conducted a study, sponsored by the Air Force Medical Support Agency, on the effects of core strength exercises on lower back pain in helicopter pilots. Active duty Air Force helicopter aircrew members assigned to Air Force Global Strike Command, Air Combat Command, Air Force District of Washington, Pacific Air Forces, and U.S. Air Forces in Europe during the period from July 2012 to September 2013 participated in the study. Participants were randomized to either three months of core strengthening exercises or continuation of their regular exercise routine.

Results demonstrated that over the course of three months, aircrew performing these exercises experienced improvements in pain severity, disability, and in the self-reported overall change in pain symptoms. This noninvasive and low-cost exercise routine may not only save the Air Force from the extended cost and treatment for those suffering with lower back pain but also, most importantly, improve the health and performance of fellow Airmen, as they support us through every helicopter mission.

Using Rigorous Statistical Techniques to Evaluate Aerial Refueling Simulator Validation Test Designs

Dr. Raymond Hill • Raymond.Hill@afit.edu • 937-255-3636 x7469

The DOD has increased its emphasis on statistical rigor for Test and Evaluation, enforced throughout a program's lifecycle to produce more affordable and efficient testing. The Center for Operational Analysis (COA) researchers supported the KC-46A Tanker program, through analyzing the efficiency of their current simulator validation test designs using statistical rigor.

An immediate challenge with this testing is that the response variables under consideration are functions of time, for which there are no formal methods of analysis; current methods of statistical rigor focus on discrete response data. This study introduced extensions to classical Response Surface Methods (RSM) specifically for modeling and exploiting time series response data. The mathematical framework is defined and demonstrated using flight data from KC-135 Aerial Refueling Simulator Upgrade testing. To supplement the RSM approach, an analysis of the statistical significance of the design parameters was conducted to determine potential linear relationships between input parameters and the response variables. Furthermore, research into computer-generated optimal designs was conducted to conclude whether the current test designs were the most effective in terms of limiting variance in the parameter estimates and the predicted response. The results revealed that more efficient and effective designs are attainable at no additional test cost.

RESEARCH Highlights

Simulating F-22 Heavy Maintenance and Modifications Workforce Multi-Skilling

Dr. Alan Johnson • Alan.Johnson@afit.edu • 937-255-3636 x4703

In collaboration with analysts at the Air Force Materiel Command's (AFMC) Depot Operations Division, researchers at AFIT's Center for Operational Analysis (COA) have provided an objective analysis of the F-22 Heavy Maintenance Modification Program located at Ogden Air Logistics Complex (ALC). This was accomplished through development of a discrete event simulation and conducting a series of experiments designed around worker multi-skilling policies. The resulting quantitative analysis provided insight on whether a multi-skilled workforce allows for more cost effective use of ALC personnel to the AFMC and Headquarters, Air Force A4 staff.

Impact to the Air Force is seen through an annual cost savings and cost avoidance of \$1.1M to \$1.6M for the F-22 Program, which supports the recommendation for multi-skilled pairings of "small with small" and "large with large" capacity specialties to offset workload demands. Research shows that the best performing multi-skilling policies are cost favorable for a given level of aircraft throughput up to the 95% efficiency level. Additionally, utilization of employees and available labor hours improves significantly with multi-skilling. A multi-skilled workforce provided more annual throughput and direct labor hour usage than a workforce of equal or greater size with no multi-skilling.

Collaborative Test and Evaluation of High Energy Laser Effects

Dr. Raymond Hill • Raymond.Hill@afit.edu • 937-255-3636 x7469

Laser threats are beginning to enter aircraft Test & Evaluation Master Plans and Operational Requirements Documents. Data relevant to aircraft are key to development of laser-enabled vulnerability assessment tools. Toward this end, the Center for Operational Analysis (COA) researchers participated in a collaborative effort with AFRL's Materials and Manufacturing Directorate and the 96th Test Group (TG) to investigate high energy laser effects on fuel-backed composite materials. Tests were performed in AFRL's lab environments and in the 96 TG's full-scale environment.

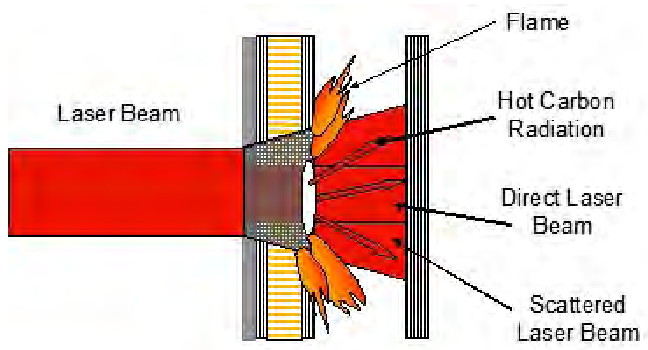


Illustration of radiation sources that can heat internal components and panels during laser exposure.

Test goals included: 1) quantifying laser threat effects on a representative subset of composite aircraft materials, 2) quantifying laser-induced structural degradation as a function of airflow cooling and backside liquid cooling, and 3) identifying and generating meaningful laser-effects datasets for transition to DOD-approved aircraft vulnerability codes. Metrics included burn-through time and fire ignition as a function of composite material thickness, laser irradiance, airflow velocity, liquid backing, and beam spot size. COA researchers determined the significance of each of these experimental factors in relation to the response metrics, in addition to determining the consistency of results both within and between test series. This was accomplished by developing predictive models using failure-time regression and residual analysis.

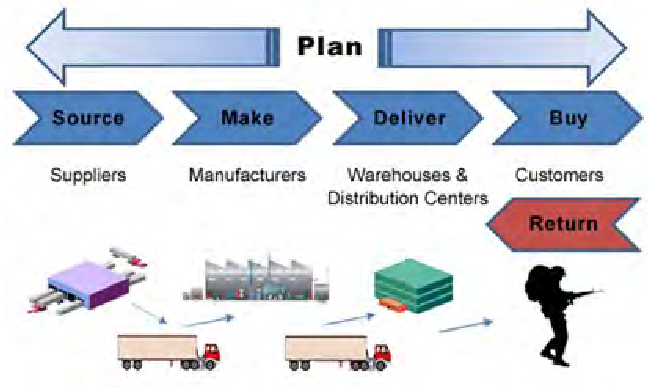
The collaborative analysis effort has impacted future test plans by establishing the factors which continue to be investigated to determine impact on vulnerability and verifying consistency in environmental conditions.

Employing the Supply Chain Operations Reference Model

Dr. Alan Johnson • Alan.Johnson@afit.edu • 937-255-3636 x4703

AFIT's Department of Operational Science hosts the Enterprise Logistics Executive Capstone Course designed for GS13-GS15 equivalent civilian and field grade officers. This four-day intensive resident program utilizes presentations, group discussions, in-class exercises, team-based overnight assignments, and competitive team-based supply chain simulations. The Enterprise Logistics Executive Capstone Course is designed around the Supply Chain Operations Reference (SCOR) model. The SCOR model–widely accepted by industry and the DOD–provides a proven framework that links business processes, metrics, best practices and technology to improve an organization's logistics outcomes.

Participants leave with a common understanding of the components of supply chain management, the importance of cross-functional and inter-firm integration, and gain an overview of the tools necessary for successful integration and alignment of the Air Force supply chain. This provides significant impact to the Air Force by affording Air Force Materiel Command Logistics senior leaders and mid-level management participants with a broad overview of the elements required for effective implementation of world-class, DOD-integrated logistics supply chain management.



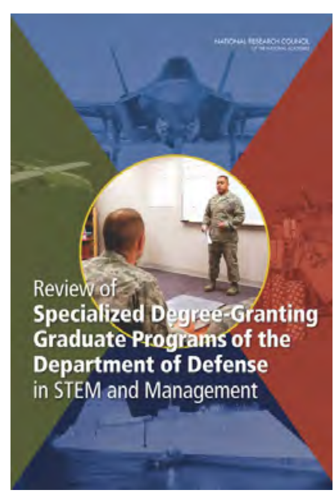
Standard roadmap of the SCOR core processes.

National Research Council Report

Review of Specialized Degree-Granting Graduate Programs of the Department of Defense in STEM and Management

In FY13, Congress directed the Secretary of Defense to work with the National Research Council of the National Academies to conduct a "Review of Specialized Degree-Granting Graduate Programs of the Department of Defense in STEM and Management." The study focuses primarily on AFIT and the Naval Postgraduate School (NPS). The study report, which was publicly released in June 2014, recognizes the value that AFIT brings to the Air Force and DOD. The study's six major recommendations are supportive of STEM graduate education in general and of both AFIT and NPS.

The study findings and recommendations were briefed to the Secretary of the Air Force, Chief Secretary of the Air Force, and provided to Congress. AFIT has reviewed the report findings and recommendations in detail, with the goal of identifying innovative actions we can take to improve AFIT's value to the Air Force and DOD even more. A copy of the report is available at www.nap.edu/catalog/18752.



FACULTY Highlights

Dr. Charles Bridgman
Order of the Nucleus

Dr. Charles J. Bridgman, Professor Emeritus of Nuclear Engineering, was inducted into the "Order of the Nucleus" on December 10, 2013. The "Order of the Nucleus" is an Air Force Nuclear Weapons Center award presented to those who are supporting, and have supported, the nuclear enterprise with great distinction.

Dr. Bridgman has been associated with nuclear weapon defense since 1952. He was a member of the first military team to be operational on the H-bomb. His current research interest is nuclear weapon fallout modeling. In his 38 years on the AFIT faculty, he has chaired over 120 MS theses and PhD dissertations. He has received several awards and is a Fellow of the American Nuclear Society.

Dr. Marina Ruggles-Wrenn
2014 Stinson Trophy

The National Aeronautic Association selected Dr. Marina Ruggles-Wrenn, Professor of Aerospace Engineering, as the recipient of the 2014 Stinson Trophy. The award recognizes a living person for an outstanding and enduring contribution to the role of women in the field of aviation, aeronautics, space, or related sciences.

Dr. Ruggles-Wrenn was selected for the award for dedicating over 27 years of her professional life to advancing the state-of-the-art in aerospace structures, design, and materials. Throughout her career, Dr. Ruggles-Wrenn has served as an innovator in aerospace materials design and testing. Her research and ability to effectively mimic real-world conditions has helped to identify limitations in a material's performance that may affect flight safety.

Dr. Peter Collins
2013 Harold Brown Award

Dr. Peter Collins, Associate Professor of Electrical Engineering, was presented with the 2013 Harold Brown Award for his research on weapons systems survivability. The Harold Brown Award is the Air Force's highest award given to a scientist or engineer, who applies scientific research to solve a problem critical to the needs of the Air Force.

Dr. Collins developed several new signature reduction and radar techniques to improve weapon system survivability and effectiveness. Most notably, his radar cross section measurement concept, which has been submitted for a U.S. patent, demonstrated a three order-of-magnitude reduction in contaminating clutter.

Dr. Glen Perram
2013 Air Force Outstanding Scientist/Engineer Award

Dr. Glen Perram, Professor of Physics, Department of Engineering Physics, was awarded the 2013 Air Force Outstanding Scientist/Engineer Award—Senior Civilian Category. His research interests include high-power chemical lasers, optically-pumped gas phase lasers, laser-material interactions, hyperspectral imaging, reaction kinetics, atomic and molecular spectroscopy, environmental science, photochemistry, optical diagnostics, and remote sensing. He has advised 32 PhD and 48 MS students, received 46 research grants, and published over 78 journal articles during his 25 years on the AFIT faculty.

Dr. Richard Martin
2014 Air Force Outstanding Science and Engineering Educator Award

Dr. Richard Martin, Professor of Electrical Engineering, was awarded the 2014 Air Force Outstanding Science and Engineering Educator Award.

During 2013, Dr. Martin taught four sections of two graduate courses and achieved near-perfect student evaluations. He contributed to the Cyber 300 professional development course, developed activities for K-12 outreach, and submitted a journal paper on game-centric curriculum design. He was also on three curriculum-related committees, including chairing the academic resources committee and organized the ongoing assessment of the graduate electrical engineering curriculum.

His research interests include: source localization; navigation via signals of opportunity; equalization for multicarrier communication systems; blind, adaptive algorithms; sparse adaptive filters; and laser radar image enhancement. He has authored 33 journal papers, 60 conference papers, one book chapter, and has five patents to his credit. Google scholar lists over 1,000 citations of his papers.

Dr. Martin received a dual BS in Electrical Engineering and Physics from the University of Maryland, and his MS and PhD in Electrical Engineering from Cornell University.

Journal Editorial Achievements

AFIT Faculty have been very active not only publishing their research findings but also serving as editors, associate editors, and editorial board members in numerous prestigious journals including:

Dr. Richard Deckro, Professor of Operations Research, is the editor of *Military Operations Research*.

Dr. Joseph Pignatiello, Professor of Operations Research, serves on the editorial review boards of *Quality Engineering*.

Dr. Mark Reeder, Associate Professor of Aerospace Engineering, currently serves as the editor-in-chief of the *International Journal of Micro Air Vehicles*.

Dr. Marina Ruggles-Wrenn, Professor of Aerospace Engineering, is a member of the Editorial Board of *Applied Composite Materials – International Journal for the Science and Application of Composite Materials*. She is also currently serving as an Associate Technical Editor of the *ASME Journal of Pressure Vessel Technology* and has served in that capacity previously (1996-2002).

Dr. Eric Swenson, Associate Professor of Aerospace Engineering, is a Technical Area Editor for the *Journal of Small Spacecraft*.

Excellence in Education Honorees

Ohio Magazine recognizes outstanding teachers at colleges and universities around the state. The following AFIT faculty members were recognized in the December 2013 issue:

Dr. Benjamin Akers, Department of Mathematics and Statistics
Dr. John McClory, Department of Engineering Physics
Dr. Barry Mullins, Department of Electrical and Computer Engineering
Dr. Marc Polanka, Department of Aeronautics and Astronautics

ALUMNI Highlights

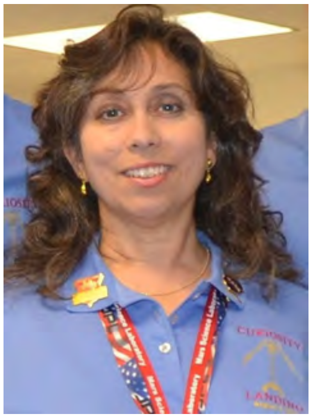
Lt Col Christopher Hammond
Thunderbirds' New No. 1

Lt Col Christopher Hammond has joined the U.S. Air Force Air Demonstration Squadron "Thunderbirds" as the squadron's commander and lead pilot. He will have the unique dual responsibilities of commanding a force of commissioned officers and enlisted service members assigned to the squadron, along with leading all demonstration flights that are designed to highlight some of the maximum capabilities of the F-16 Fighting Falcon.

Lt Col Hammond earned his master's degree in cyber warfare at AFIT in 2011. "My degree from AFIT has helped in many aspects of my career so far. It took me out of my comfort zone and exposed me to a discipline that I didn't have a background in. As a result I became better prepared for follow-on assignments. Earning an AFIT master's degree in cyber warfare exposed me to both the space and cyber domains and ultimately enhanced my overall perspective and understanding of the greater Air Force mission."

The Thunderbirds will begin their show season in March 2015. This will be the squadron's 62nd season as the Air Force's premier jet demonstration team. From mid-March until mid-November, the team travels around the country and abroad, showcasing the pride, precision, and professionalism embodied by American Airmen serving around the world.

Zainab Nagin Cox
From AFIT to Mars



Following her commission into the Air Force, Ms. Zainab Nagin Cox was stationed at Wright-Patterson AFB where she worked as a systems engineer in F-16 aircrew training. She graduated from AFIT in 1990 with a master's degree in Space Operations Systems Engineering.

She served as an Orbital Analyst at North American Aerospace Defense Command/ Space Command in Cheyenne Mountain, Colorado Springs and retired from the Air Force in 1992. She is currently a Spacecraft Systems Engineer at the National Aeronautics and Space Administration's (NASA) Jet Propulsion Laboratory (JPL) operated by the California Institute of Technology in Pasadena, California. JPL is one of 10 NASA centers and is the leading U.S. center for the robotic exploration of the solar system. Ms. Cox has worked on multiple robotic missions during her civilian career. Her role as a system engineer has been focused on development at the flight ground interface. She is one of several engineers who leads the development of the commands that execute on the Mars Rover.

"The classes in propulsion, astrodynamics, spacecraft systems, orbital dynamics, and spacecraft operations have served me very well, even at NASA, because it taught me the language of space operations by providing the basics of what I needed to know in all of these different areas." At the time, her thesis advisor, Dr. Matthew Kabrisky, was conducting research on epilepsy drugs and their effectiveness to treat motion sickness in pilots. While it was not directly applicable to her space operations degree, the program was flexible enough that she was able to complete research for her thesis work. "It was a good example of teaching something indirectly–teaching me how to be flexible in my thinking and finding a match in people's skills to let them do what they are good at and what they are interested in. That can be more productive than being forced into a particular box."

AFIT Distinguished Alumni Awards

From left to right: President of the AFIT Foundation Dr. Robert Calico; Maj Gen Jeffrey Riemer, USAF (Ret); Dr. Stephen Cross, USAF (Ret); and AFIT Chancellor Dr. Todd Stewart. Not pictured: Brig Gen Charles Winters, USAF (Ret).

Maj Gen Jeffrey Riemer, Brig Gen Charles Winters, and Dr. Stephen Cross were honored with the AFIT Distinguished Alumni Award at the 95th Anniversary and Distinguished Alumni Awards ceremony on October 2, 2014. The award is the highest honor that AFIT can bestow upon a graduate. Since 1979, 30 other individuals have been selected.

Maj Gen Jeffrey Riemer, USAF (Ret)

Maj Gen Jeffrey Riemer entered the Air Force in 1974 after graduating from the University of Florida ROTC program. He was an F-16 acceptance test pilot at General Dynamics, when he was selected to attend AFIT and Test Pilot School. After graduating in 1984 as a distinguished graduate of both schools with a Master's of Science degree in aeronautical engineering, he remained at the Test Pilot School as an instructor and continued his experimental test pilot duties with the F-16 Combined Test Force. Gen Riemer has served in numerous positions within the test and acquisition community. His last assignment was the Air Force Program Executive Officer for the F-22, where he was responsible for all acquisition activities--a $70 billion program with 1,000 suppliers in 44 states. He currently serves as the Chief Operating Officer for InDyne, Incorporated where he is responsible for operations and developing and implementing strategic initiatives.

Brig Gen Charles Winters, USAF (Ret)

Brig Gen Charles "Pete" Winters was a graduate of the U.S. Air Force Academy's first class in June 1959. After completing F-100 tactical training at Luke Air Force Base in Arizona, and Nellis Air Force Base in Nevada, he served in Japan, South Carolina, Turkey, and Italy. Gen Winters attended AFIT where he earned a Master of Science degree in Aerospace Engineering. He was then stationed at Phan Rang Air Base in the Republic of Vietnam where he flew 298 combat missions in the F-100. In 1988, Gen Winters retired from active duty. In 2000, he formed a corporation called Joint Test Training and Technical. His company has been involved in testing such aircraft as the F-35 Lightning II, F-117 Nighthawk, B-2 Spirit, and F-22 Raptor. He retired from the company on December 31, 2004 but has continued to serve as a consultant and advisor.

Dr. Stephen Cross, USAF (Ret)

Dr. Stephen Cross is the Executive Vice President for Research, and professor in the H. Milton Stewart School of Industrial and Systems Engineering. He is also an adjunct professor in the College of Computing at the Ernest J. Scheller College of Business at the Georgia Institute of Technology. Dr. Cross retired from active duty with the United States Air Force in 1994 with the rank of Lieutenant Colonel. His military assignments included service as an engineer in acquisition program offices and flight test programs, a faculty member at AFIT, and a program manager at the Defense Advanced Research Projects Agency (DARPA). His association with AFIT spans time as a resident student in an engineering master's program from 1976 to 1977, a doctoral program student through the civilian institute program from 1980 to 1983, and service as a faculty member in the Graduate School of Engineering and Management from 1983 to 1987.

Selected Large Awards for FY14

"Increasing the Federal Cybersecurity Workforce through Graduate Education and Research at AFIT"
$838K - National Science Foundation
Principal Investigator: Dr. Rusty Baldwin

"The Science of Test: Advanced Test and Evaluation in Support of the DOD Test and Evaluation Enterprise"
$796K - Office of the Secretary of Defense
Principal Investigator: Dr. Raymond Hill

"GNSS Testbed Development"
$665K - AFRL Sensors Directorate
Principal Investigator: Dr. John Raquet

"HELJTO M&S TAWG Product Development"
$500K - High Energy Laser Joint Technology Office
Principal Investigator: Dr. Steven Fiorino

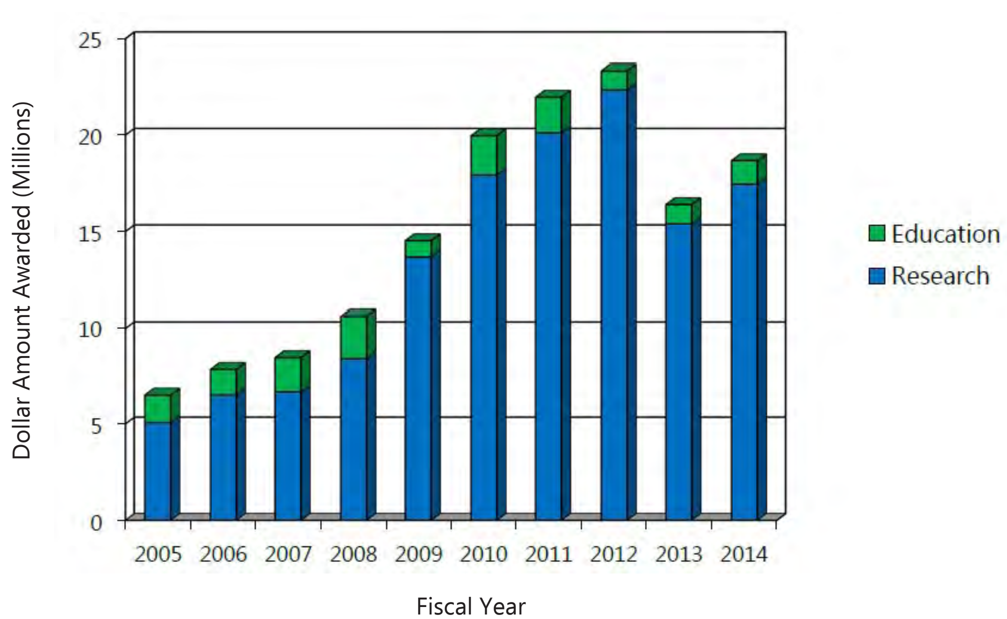
"Support for Adaptable Navigation Systems Program"
$470K - Defense Advanced Research Projects Agency
Principal Investigator: Dr. John Raquet

"Research, Analysis and Transition Support to the Directorate of Logistics and Sustainment, Air Force Sustainment Center"
$440K - Air Force Sustainment Center
Principal Investigator: Dr. Alan Johnson

"Overhead Persistent Infrared (OPIR) Research and Algorithm Development"
$375K - National Geospatial-Intelligence Agency
Principal Investigator: Dr. David Bunker

"Nuclear Survivability Experimentation, Modeling, and Data Verification"
$320K - Air Force Nuclear Weapons Center
Principal Investigator: Dr. James Petrosky

New Award History FY05-FY14



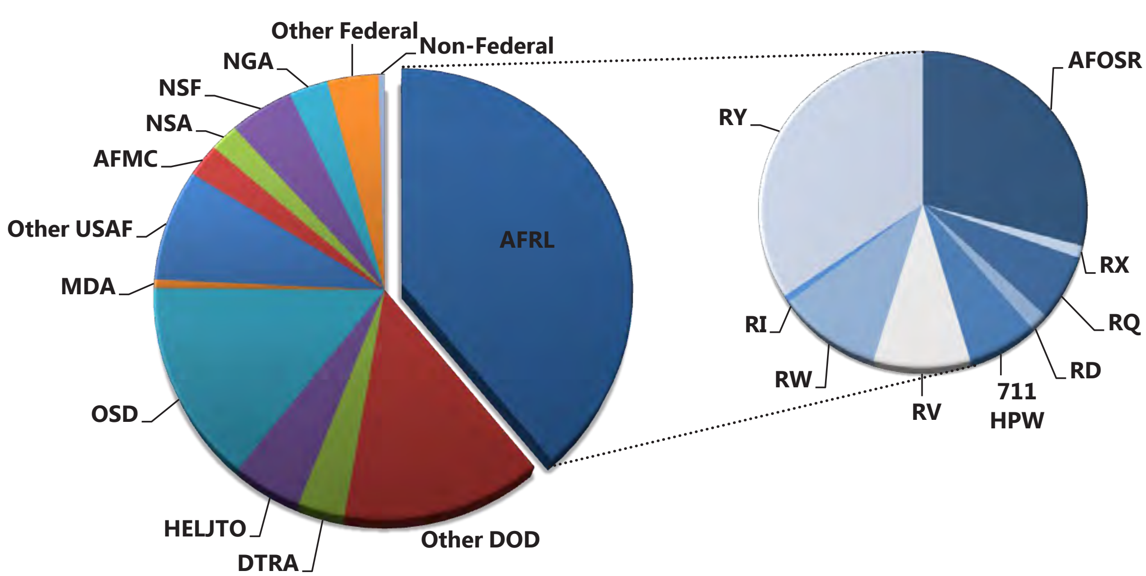
New FY14 Awards to Academic Departments and Research Centers

DEPARTMENT	*Newly Awarded Research Projects* #	*$k*	*Newly Awarded Education Projects* #	*$k*	*Total FY14 Newly Awarded Projects* #	*$k*	*Total FY14 Research Expenditures* *$k*
Mathematics & Statistics (ENC)	5	318	1	13	6	331	334
Electrical & Computer Eng (ENG)	69	5,713	3	1,016	72	6,729	7,811
Engineering Physics (ENP)	44	4,144	1	9	45	4,153	5,630
Research & Sponsored Programs (ENR)	1	19	-	-	1	19	-
Operational Sciences (ENS)	17	4,028	5	145	22	4,173	3,923
Systems Eng & Management (ENV)	14	678	-	-	14	678	1,280
Aeronautical & Astronautical Eng (ENY)	44	2,522	2	50	46	2,572	4,583
TOTAL	**194**	**17,422**	**12**	**1,233**	**206**	**18,655**	**23,561**

CENTER	#	$k	#	$k	#	$k	$k
Autonomy and Navigation Technology (ANT)	30	3,104	-	-	30	3,104	3,677
Center for Cyberspace Research (CCR)	10	648	2	1,013	12	1,661	1,186
Center for Directed Energy (CDE)	22	2,128	1	9	23	2,137	2,544
Center for Operational Analysis (COA)	17	3,953	5	145	22	4,098	3,790
Center for Space Research and Assurance (CSRA)	16	1,347	-	-	16	1,347	2,414
Center for Tech Intel Studies & Research (CTISR)	7	916	-	-	7	916	1,474
TOTAL	**102**	**12,096**	**8**	**1,167**	**110**	**13,263**	**15,085**

Note: Total research expenditures reported include institutional cost sharing, which is not included in newly awarded projects. Numbers reported to the ASEE and NSF research expenditure surveys vary somewhat due to differences in definitions. All Center funds are also included in departmental funding.

Sponsors of FY14 Projects



*Pie chart on the right shows breakdown by AFRL Technology Directorates.

Enrolling at AFIT for Graduate Studies

The Graduate School of Engineering and Management offers multiple graduate and doctoral degree opportunities that focus on high-quality graduate education and research. We serve the Air Force as its graduate institution of choice for engineering, applied sciences, and selected areas of management. The appeal for our distinct educational opportunities is widespread and attracts high-quality students from other US armed services, Government agencies both inside and outside the DOD, and international military students. Of particular note, under the National Defense Authorization Act for Fiscal Year 2011, the Graduate School may enroll defense industry employees seeking a defense-related master's or doctoral degree. Tuition will be waived for all Air Force military and Air Force civilians, who are not sponsored by the Air Force to enroll at AFIT on a space-available basis.

Our automated application system provides immediate application information to the Office of Admissions, and there is no application fee. Because of our highly-automated admission processes, the Office of Admissions usually renders an admission decision within 21 days.

Prospective students will join a robust and energetic student body focused on learning and research. The Accreditation Board for Engineering and Technology (ABET) accredits all of our eligible engineering programs. Students usually finish their master's programs within two years and the doctoral programs within three years. Enrollment averages around 700 full- and part-time students with a student-to-faculty ratio of 5:1. In academic year 2013-2014, 330 master's and doctoral degrees were awarded to 261 AF officers, 5 AF enlisted, 22 sister services, 29 civilians, and 13 international military officers. Our campus consists of eight buildings, 23 class laboratories, 67 research/laboratory areas, and the D'Azzo Research Library.

For more information, visit www.afit.edu/en/admissions/index.cfm.

AFIT Internship Opportunities

Internship opportunities are available for undergraduate and graduate science, technology, engineering, and mathematics (STEM) students through the Southwestern Ohio Council for Higher Education (SOCHE). Students have the opportunity to work at AFIT through the Summer Internship Program, the Student Research Program, or both. Students benefit both academically and financially by working in state-of-the-art laboratories with top professionals in their field. Additionally, they can use this experience for senior projects, cooperative education, and graduate research. AFIT receives the benefit of top students, who bring new energy and ideas to the research projects.

For additional information regarding AFIT internship opportunities visit www.socheintern.org/.

AFIT Research Centers

Air Force Center for Cyberspace Technical Excellence Center for Cyberspace Research	www.afit.edu/en/ccr/	Dr. Robert Mills
Autonomy and Navigation Technology Center	www.afit.edu/en/ant/	Dr. John Raquet
Center for Directed Energy	www.afit.edu/en/de/	Dr. Steven Fiorino
Center for Operational Analysis	www.afit.edu/en/coa/	Maj Brian Stone
Center for Space Research and Assurance	www.afit.edu/en/csra/	Col Matthew Sambora
Center for Technical Intelligence Studies & Research	www.afit.edu/en/ctisr/	Dr. Kevin Gross
OSD Scientific Test and Analysis Techniques Center of Excellence	www.afit.edu/en/stat_te_coe/	Dr. Darryl Ahner

Sponsoring Thesis Topics

AFIT encourages input from your agency that aligns our research and student education to relevant areas to ensure the technological superiority and management expertise of the U.S. Air Force and the DOD. Each topic submitted has a strong positive impact on AFIT's ability to focus on research relevant to real-world requirements. For more information, please contact the Office of Research and Sponsored Programs: research@afit.edu.

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