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The Advanced Guided Weapon Testbed (AGWT) at the Air Force Research Laboratory Munitions Directorate

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This article describes the capabilities of the Kinetic Kill Vehicle Hardware-in-the-Loop Simulator facility and the Virtual Munition Simulator facility co-located at the U.S. Air Force Research Laboratory Munitions Directorate, Eglin Air Force Base, Florida. Together they make up the Advanced Guided Weapon Testbed used to research advanced guidance components using hardware-in-the-loop simulation as well as the exploitation and investigation of new weapon concepts through the use of distributed simulation and wargaming.

Key words: Autonomous guided munitions; capabilities; communication; cooperative attack; hardware-in-the-loop simulation; human-in-the loop; synthetic scene generation; wargaming.

The U.S. Air Force Research Laboratory Munitions Directorate's (AFRL/RW) mission is to develop, integrate, and transition science and technologies for air-launched munitions for the defeat of ground, air, space, and cyber targets. These technologies advance warfighter capabilities through the development of guided munitions that operate autonomously or semi-autonomously to acquire, track, engage, and kill moving and fixed targets. Many of these new weapon systems are becoming highly communicative and rely on multi-sensor data fusion, human-in-the-loop confirmation, and increased fire control for cooperative attack.

AFRL/RW shares the Department of Defense (DoD) and Air Force vision that synthetic, or virtual, testing of these increasingly complex weapon systems will play a critical role in future success on the joint battlefield. To determine which guided weapon concepts and technologies are the most beneficial to the warfighter, they need to have a good understanding of the kind of capabilities that advanced technology can bring to the joint and coalition battlefield. The Advanced Guided Weapon Testbed (AGWT) allows for improved system effectiveness on the battlefield by getting advanced weapons' concepts into the hands of the warfighter early in the weapons life cycle, providing an optimized solution, maximizing interoperability, and reducing risk and cost by utilizing a high fidelity simulation to augment flight tests.

Made possible by the investment and direction of the Missile Defense Agency (MDA) since 1987, and with the addition of Air Force funding in more recent years; the Kinetic Kill Vehicle Hardware-in-the-Loop Simulator (KHILS) facility mission focuses on high fidelity hardware-in-the-loop (HWIL) simulation of guided hit to kill weapons (Murrer, Thompson, and Coker 1999). KHILS serves as a testbed for development of HWIL test technologies for agencies around the country, such as scene projectors, projector control electronics, high frequency motion simulation, and synthetic scene generation. KHILS also performs Government-owned nondestructive HWIL testing for guided munition hardware and software component research, development, and test (such as infrared [IR], Ladar, ultra-violet [UV], millimeter wave [MMW], and visible seekers; navigation systems; advanced guidance algorithms; flight hardware and software; and integrated guidance systems). Use of the KHILS for ground test reduces the number of flight tests needed for critical program decisions, provides risk reduction for those flight tests that do take place, and provides expanded operational envelope definition by investigating off-nominal scenario excursions. All of these roles help to lower overall flight test costs.

The Virtual Munition Simulator (VMS) facility provides a persistent distributed simulation connectivity to enable advanced guidance, sensor, and other advanced munition technologies and concepts to play in distributed joint experiments in the engineering, testing, and training domains. It supports virtual and

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constructive simulation of advanced conceptual weapons, and components, with or without a human-in-the-loop. The VMS leverages state-of-the-art expertise from multiple disciplines including persistent distributed environments, constructive/virtual simulations, HWIL, munitions and targets modeling, guidance, navigation, and control, real-time scene generation, and seekers, sensors, and signal processing. Without this early interaction, weapon systems brought to the field will suffer inadequacies in meeting the warfighter needs, and modification costs to meet these needs will be high. Having advanced weapon concepts used in joint war-gaming and training games/events gives the warfighter a chance to explore and exploit new technologies, make suggestions for improvements/modifications, help determine the Concept of Employment (CONEMP), and, overall, impact the technology maturation decision process early in the life cycle providing the best use of dollars to meet their needs. By having new weapon concepts accepted and vetted by the warfighter early in their life cycle, the weapons developed by the Air Force will continue to play an important role in the success of the warfighter on the battlefield at a lower cost.

Both facilities together combine to comprise the state-of-the-art 10,000 plus square foot AGWT, consisting of high throughput computational resources, physical effects simulators, environmental chambers, scene projectors, synthetic scene generation, and flight motion simulators, which realistically exercise integrated guided missile concepts in a simulated flight environment. This testbed is helping in research, development, test, and evaluation (RDT&E) of advanced weapon concepts, sensors, multi-source sensor/data fusion, weapon targeting, and guidance algorithms in a joint netted environment. In addition, the AGWT provides an environment for flight test risk reduction studies uncovering hardware and software issues that could jeopardize the success of a flight test. All evaluations can be performed as stand-alone internal research activities or as part of a distributed simulation capability in either unclassified or classified environments.

AGWT resources

Constructive/virtual/real-time simulation computational resources

The heart of any simulation capability begins with the computers that run the software that is simulating the vehicle and its environment, and there is a great deal of computational capability in these facilities. The AGWT computational equipment suite is a collection of computer systems uniquely configured and integrated to support real-time simulation, high volume data reduction, and the hardware and digital model interfacing requirements of HWIL and distributed simulation.

i-Hawks. Three modular concurrent iHawk server systems function as the principal real-time modeling and control computers. These computers solve the missile 6 degree of freedom equations, contain models of missile subsystem components not present as hardware, and compute the target states and the engagement geometry. Miss distance requirements and the small time constants for signal processing, guidance, and propulsion subsystems demand accurate and efficient computation to keep pace with high-speed hardware test articles. Commands for the physical simulators, the flight motion simulators, and the image generation systems are also generated here.

16 CPU Beowulf cluster. This cluster performs the task of visualization for a large eight-screen data wall, as well as for the dual-seat F-15 cockpit simulator. The AGWT is currently using the commercially available FlightGear software to visualize the weapon flight environment. This suite of computers is also available to drive the instrument panels and the visible imagery available to the pilot in the F-15 cockpit simulator.

IBM Blade center. A 64-processor IBM Blade center is used primarily to perform Monte Carlo constructive simulations that are used to evaluate target acquisition, recognition, and tracking algorithms. This multiprocessor architecture is ideally suited for distributing a large quantity of runs over many processors for evaluation against numerous closing engagements and scenarios.

Dual-core Xeon PC's. Through KHILS' test technology development efforts on real-time PC-based scene generation, some aspects of HWIL simulation can now be performed with standard desktop computers. These computers are spread throughout the seven workstations and can be configured to run scene generation software, simulate operator ground control stations, or anything that needs to be computed as part of the HWIL environment.

Flight Motion Simulators (FMS)

A key aspect of performing HWIL is to accurately simulate the motion of the weapon system during flight. The FMS tables are used to impart flight-like angular dynamics to the test article's sensor, gimbals, and inertial instrumentation. The KHILS flight motion simulators are electro-hydraulic and electro-magnetic devices designed to subject the test article to high dynamic range rotational motion as might be experienced in an actual engagement. The five- and

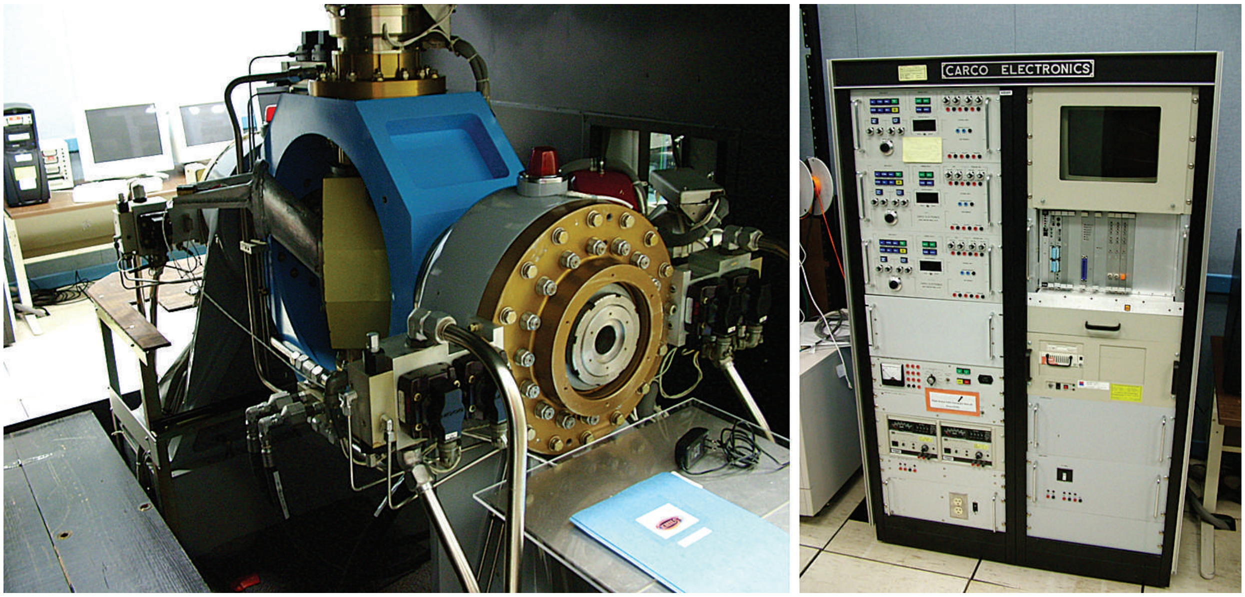

Figure 1. Carco three-axis Flight Motion Simulators and controller.

three-axis FMS are electrically commanded and hydraulically driven to achieve the high bandwidth required to simulate a closed loop engagement with large inertias and large amplitudes, whereas the high frequency motion table simulates low amplitude, small inertia jitter. The five-axis table is capable of reproducing bandwidths up to 35 Hz, while the smaller three-axis table can simulate frequencies up to 60 Hz.

Three-axis Carco table. In 1988, KHILS developed a three-axis Carco FMS, *Figure 1*, optimized for lightweight space-based interceptor concepts. Simulator range of travel was limited (+/− 10 degrees) in order to achieve, at that time, an unprecedented dynamic response of 60 Hz. Since that time, the simulator was upgraded with an interchangeable set of hydraulic actuators to allow for approximately twice the increase in travel at the expense of some bandwidth.

Five-axis Carco table. The five-axis table, *Figure 2*, delivered in 2001, allows for a larger payload mass and volume than the three-axis, and true line-of-sight simulation with target motion that can be represented by installing a projector on the outer gimbal. It also has a much larger range of travel for "over-the-shoulder" engagement scenarios.

High-frequency motion table. KHILS has developed the capability to reproduce high-frequency jitter through the use of the Image Stabilization Testbed (ISTAT) system, *Figure 3*, currently being installed in the facility. This system uses electro-mechanics to generate motion up to 1,000 Hz to simulate missile motion beyond the capability of current state-of-the-art flight motion simulators. The ISTAT can replicate the dynamic boundary conditions at the base of the seeker resulting from both airframe vibrations (flexible body motion) as well as rigid body motion (up to +/− 1 degree) resulting from vehicle control forces or the flight environment. The ISTAT is not a shaker table but is driven by the output of a deterministic closed-loop simulation and will replicate the time history of a commanded signal.

Control room

The control room comprises seven reconfigurable workstations, 14 dual-core Xeon PCs, four large LCD displays, 28 workstation displays, and an eight-screen data wall for visualization of important simulation data *(Figure 4)*.

Reconfigurable workstations and viewing area. There are seven reconfigurable workstations distributed throughout the control room. These workstations can be used to simulate ground control stations or operator–in-the-loop stations, control the simulation, manage the scenario visualization, manage the data-wall screen displays, run scene generation software, or do just about anything else that is needed during an HWIL simulation. There is also a 15-seat viewing area where invited guests can watch the simulation and get a complete picture of everything that is happening from one location. Interested parties can view the weapon system functionality from many different

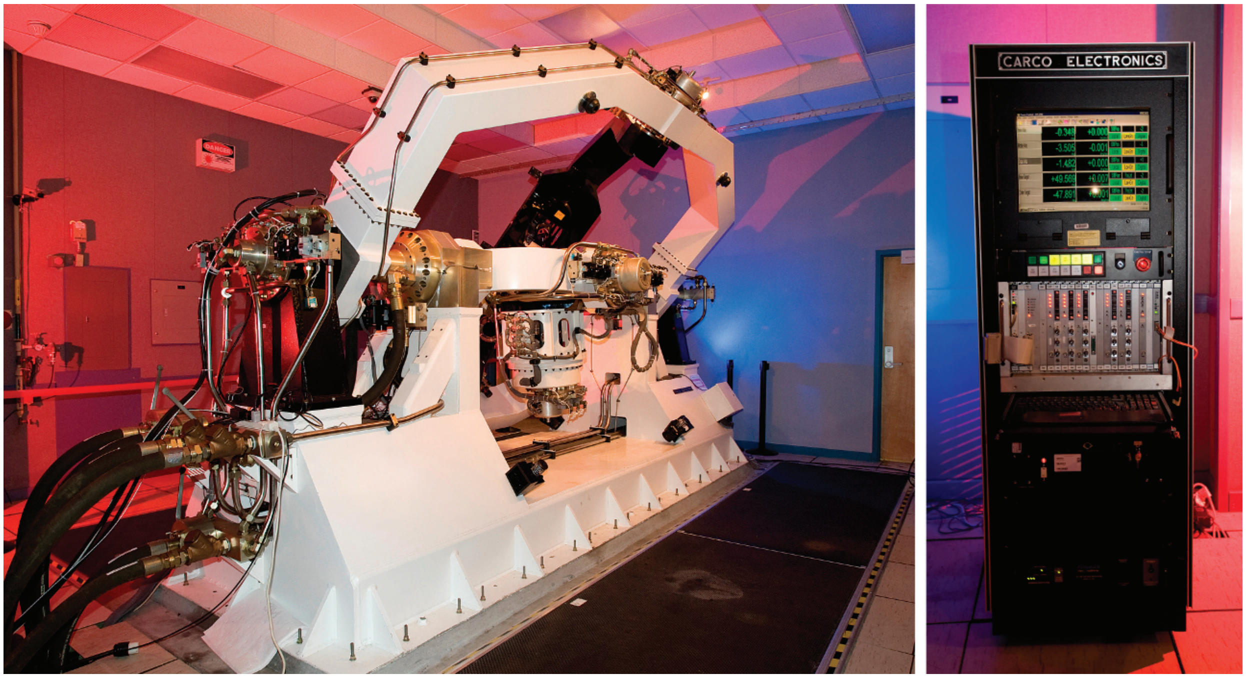

Figure 2. Carco five-axis Flight Motion Simulators and controller.

perspectives, and warfighters get a chance to experience new weapon systems and see the real hardware in live, virtual, and constructive war games and training events.

Data wall. The data/video wall, *Figure 5*, comprises individual display devices placed edge to edge to produce a larger unified display. The wall consists of eight, 52-inch LCD flat panel displays, a video wall processor, DVD-R, and a high quality sound system. The video wall can be configured to display both video and data signals. When married with its video wall processor, the wall displays a Windows desktop mirroring what you'd see on a PC. Additional inputs can be added to the video wall processor to display satellite and camera feeds, as well as DVD and VCR signals. The processor allows an operator to select network applications and to size and move them seamlessly across the video wall. The video wall can display a broad range of sources that allow the user to access and utilize the information in a consistent and intuitive way. As a monitoring tool, the video wall enhances the user's effectiveness in responding to problems as they arise. By looking at the expansive data wall and surrounding monitors, the operator can watch critical parameters of the simulation; see the projected imagery, the sensed imagery, and the autopilot functions; monitor the flight motion table; view the synthetic imagery; and access a host of other functions.

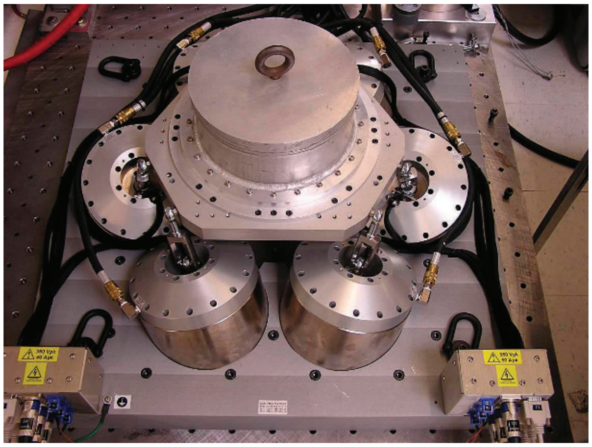

Figure 3. Five-axis high frequency Flight Motion Simulator table.

Human-in-the-loop capability

An F-15 dual seat cockpit simulator, *Figure 6*, serves to offer a human-in-the-loop capability to the testing environment. This cockpit can be used to allow a pilot to gain experience with the targeting and mission planning associated with new weapon concepts. Although originally an F-15 cockpit simulator, the cockpit display can be driven to show displays for both the front or rear seat and new functionality can be added to any screen. Important information can be gained by using feedback on workload and problems associated with launching multiple weapon systems from future platforms.

Figure 4. Control room with reconfigurable workstations (top left & right) and viewing area (bottom).

Figure 5. Data wall display.

Figure 6. F-15 dual-seat cockpit simulator.

Scene projection

The AGWT performs HWIL testing on imaging sensors having autonomous discrimination, track, and aimpoint algorithms, requiring a robust projection capability. There are numerous types of scene projectors that have been developed for use in KHILS as well as by many other HWIL facilities (Williams, Goldsmith, and Stockbridge 2005). This gives us the capability to project synthetic imagery to the units under test in the specific waveband they expect to see during an actual flight. We currently have projectors in the infrared (IR), visible, and Ladar wavebands.

Infrared scene projection. Infrared scene projection capability has grown rapidly in KHILS to include the Wideband Infrared Scene Projector (WISP), the Multi-Spectral Scene Projector (MSSP), and the Optimized Array for Space-background Infrared Simulation (OASIS). *Figure 7* shows a 512 × 512 IR MSSP projector along with its associated collimator optics that collimates the light and focuses the image at infinity.

Figure 8 shows a 512 × 512 programmable high dynamic range resistive array IR OASIS projector. The OASIS array is optimized to operate in cryogenic chamber environments; however, it will also function very well at room temperature. High fidelity synthetic IR imagery is projected through this device to a seeker unit under test. The generation of this imagery is described in the Synthetic Scene Generation section.

Imagery from two or more devices can be combined through a diachronic beam combiner to present multiple waveband imagery to a seeker under test (Sieglinger 2006). Each resistor in the array, or pixel, is individually controlled by regulating the current flow through the resistor, thus regulating the resistor's radiance output. This allows KHILS to test the full functionality of the seeker including optics, focal plane array, and processor.

Ladar scene projection. Several organizations in the DoD are developing Ladar seekers, and it is necessary to be able to stimulate these articles in a HWIL test environment. An ongoing effort to develop a large-format Ladar scene projector has been underway for several years. KHILS has already demonstrated the capability to digitally inject synthetic Ladar imagery to a sensor under test. Research programs are now underway to develop a 256 × 256 Ladar scene projector capable of providing imagery to the next generation of Ladar seekers. An eight-channel Ladar scene projector has been used for previous weapon seeker testing. Because of its large size, if we were to expand this to 65,000+ channels we would need a new building to hold all the racks of equipment. Numerous research projects into laser diodes, arbitrary waveform generators, photonic modulators, high-speed D to A converters, and many other areas will allow us to develop the next generation Ladar scene projector in a fraction of the space.

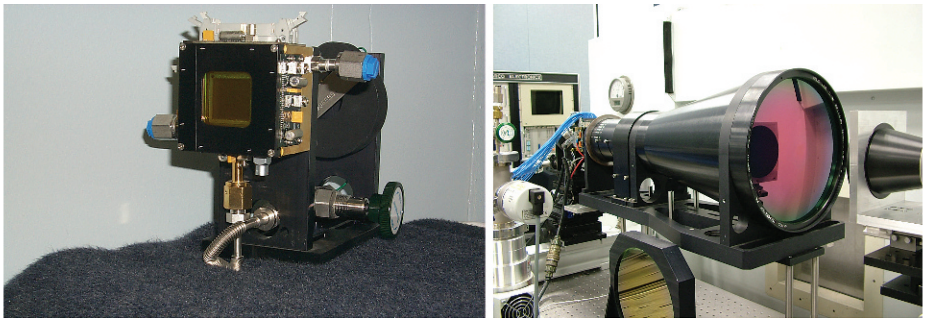

Figure 7. Multi-Spectral Scene Projector infrared projector (left), collimator optics (right).

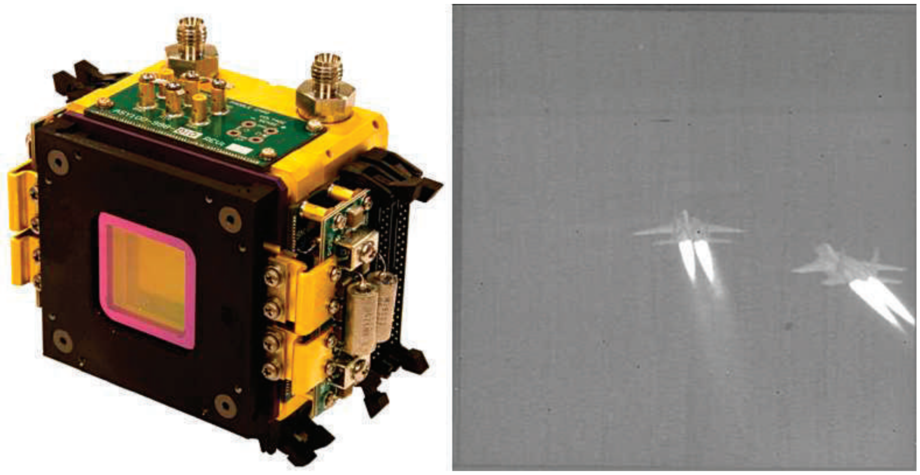

Figure 8. Optimized Array for Space-background Infrared Simulation 512 × 512 infra-red scene projector (IRSP) (left), raw imagery captured with infrared camera (right).

Visible scene projection. New weapon system seekers are being developed with much wider fields of view than previous seekers. The AGWT has recognized the need to stimulate those sensors during HWIL testing, and in 2009, a Wide-Field-Of-View (WFOV) visible multi-projector system, *Figure 9*, is being installed in the AGWT. The WFOV projector system is a 4-meter dome, which uses 10 projectors to produce an image that is 220 degrees in azimuth and 135 degrees in elevation. Research into an IR WFOV projector system is beginning as well.

Projector array control electronics. Through KHILS' technology development efforts in array control electronics, talented engineers have designed the PC-based Array Control Electronics or PACE (Goldsmith et al. 2003). PACE is an inexpensive, robust, and reconfigurable set of electronics that can support legacy, current, and upcoming emitter array projectors. The PACE electronics systems are manufactured and tested in the KHILS facility and have been successfully transitioned to numerous MDA, Air Force, U.S. Army, and U.S. Navy test facilities.

Infrared projector characterization

KHILS has established a nationwide reputation as an expert in non-uniformity correction (NUC) of resistive array IR scene projectors. These types of projectors suffer from an inherent non-uniformity among the individual elements. The uncorrected elements may exhibit 10 to 20 percent spatial variation when commanded with the same drive voltage. Methods have been developed over the past decade for NUC of resistor array projectors. After correction, the element response variation can be reduced to the order of a percent or two, depending mainly on the NUC camera errors (Flynn et al. 2003; Joyce, Świerkowski, and Williams 2006; Meshell et al. 2008; Sisko et al. 2006).

Figure 9. Visible wide-field-of-view projector system.

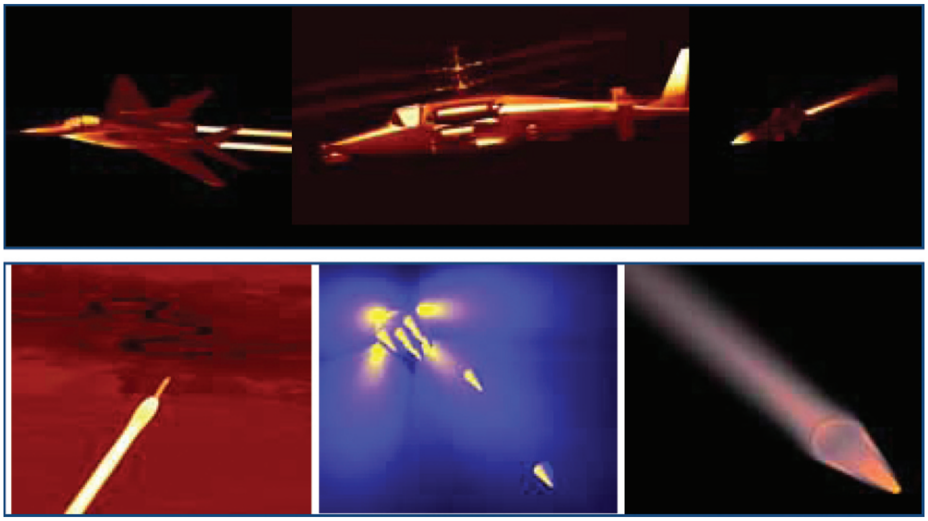

Figure 10. Air breathing and ballistic missile real-time CHAMP outputs in various wavebands.

Synthetic scene generation

To provide inputs to all of these different types of scene projectors, we have an extensive real-time synthetic scene generation capability. The AGWT's primary function relates to high fidelity endgame simulations of visible, IR, MMW, and Ladar seekers, and the closing guidance sequences require that KHILS engineers merge aerodynamics, 6 degree of freedom analysis, aerodynamic heating, and signature predictions in a real-time sequence. The code used to generate these images in the AGWT is called the Real-Time Composite High Altitude Missile Plume (RTC) code.

RTC began as a code called Composite High Altitude Missile Plume (CHAMP) (Crow and Coker 1998), developed by KHILS in the late 1980s as a tool to render complex targets, such as missiles with fins, multi-warhead post-boost vehicles, and waking reentry vehicles. CHAMP incorporates the time-dependent signature phenomena, based on computed hard-body thermal response owing to radiation and convection heat loads. It also models external source effects, including solar reflection, earth shine, and plume impingement. Over the years, the CHAMP code has been updated to include modeling of tactical air breathing targets such as aircraft, cruise missiles, maritime, and ground-based targets. It has also been made to run real-time for use as RTC for performing HWIL simulations. *Figure 10* shows examples of RTC output for ballistic missiles and air breathing threats. *Figure 11* shows some examples of maritime and ground-based target imagery generated with the RTC code.

As urban combat has become an important part of the warfighter's mission, the AGWT is developing a capability to exercise advanced weapons with realistic synthetic urban imagery in real time. The capability to generate urban scenes as high fidelity, spectrally correct images has been completed under a Small Business Innovative Research (SBIR) program with TerraSim using their product TerraTools *(Figure 12)*. Work is currently ongoing to merge the urban scene generation with RTC to provide a real-time capability for use in the HWIL environment.

Environmental chambers

Some weapon systems are designed to operate in unique operational backgrounds, or require special environments for repeatable high fidelity ground testing. KHILS has several unique capabilities to provide the appropriate operational environment for HWIL testing.

Cryogenic chamber. The first is the KHILS Vacuum Cold Chamber (KVACC). The KVACC consists of a cooled optical collimator and source chamber inside a vacuum chamber in a class 1000 clean room and has established the capability to perform IR scene projection for HWIL testing with significantly reduced IR backgrounds. The cold background of this system reduces the overall thermal noise floor, thereby increasing the available dynamic range of the projection system. The all-reflective optics in KVACC provides the capability of simultaneous mid-wave and long-wave IR scene projection. A sensor chamber has been added to the main KVACC chamber, providing for testing of seeker hardware and/or vacuum-capable IR cameras. Also, a gaseous helium refrigeration system has been installed, greatly reducing the logistics and operational overhead of dealing with LN2. The

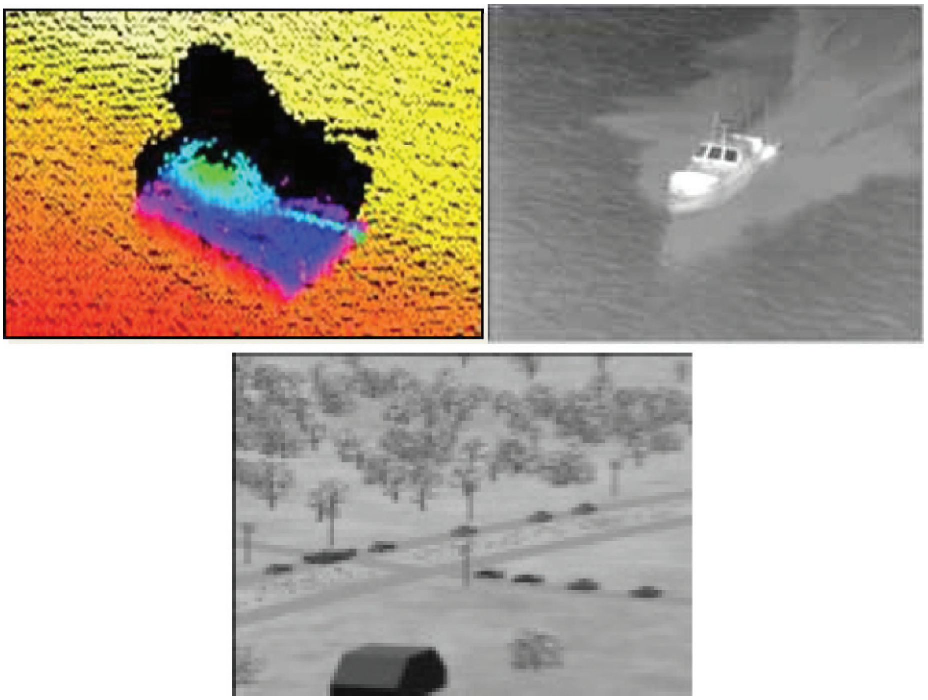

Figure 11. Ground and maritime real-time CHAMP output in various wavebands.

new refrigeration system provides a chill-down capability to about 50 to 60 K (Thompson et al. 2006).

Radio Frequency (RF) environmental chamber. The AGWT also includes a 21 × 26 × 16 foot tall X-band anechoic chamber located in a 100-dB shielded room to accommodate ground testing of RF systems. There is a moveable flight table mount that allows a flight table to be inserted into the middle of the room for articulation of test articles inside the chamber. There is an antenna array wall at the other end with access to the RF chamber.

Global Positioning System (GPS) simulator

As GPS is an important function for many weapon systems, the AGWT has the capability to simulate a fully operational GPS environment using the Interstate Electronics Global Positioning System. The GPS simulator can provide up to 24 channels of L1/L2 satellite information to a missile system.

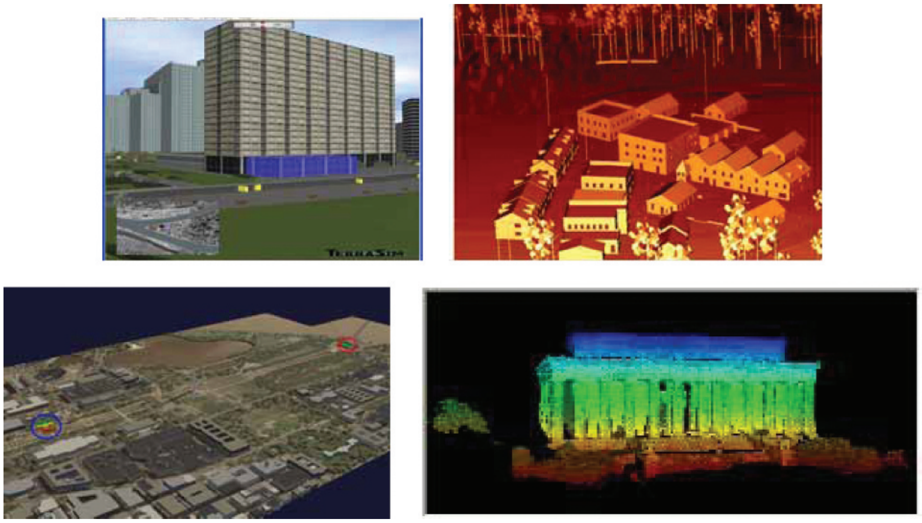

Figure 12. Urban scene generation examples in various wavebands.

Distributed connectivity

The AGWT is capable of connecting to the outside world through many different networks including the Defense Research and Engineering Network (DREN), the secret form of the DREN known as the SDREN, MDA-Net, and the Joint Mission Environment Test Capability (JMETC) virtual private network. The AGWT can operate in both classified and unclassified modes. This connectivity has been used with several war games and joint experiments including the Joint Expeditionary Forces Experiments (JEFX) and the Advanced Concept Exploration (ACE) experiments.

Summary

KHILS has long been recognized as a national test resource for the development of HWIL test technology and the nondestructive HWIL performance testing of precision guided missile systems and subsystems. With the recent addition of the Virtual Munition Simulator, the AGWT is the Air Force Research Lab's one-stop shop for researching and demonstrating advanced weapon system components and systems through HWIL and distributed simulation. AGWT test engineers provide pretest planning, integration, test execution, data observations and collection, and posttest data analysis on a variety of guidance subsystem technologies.

While the AGWT prides itself in being a leader in the design of scene projectors and electronics, synthetic scene generation, distributed simulation, and PC-based real-time hardware, the facility offers much more. It is more than a facility filled with computers, hardware, software, and electronics. The AGWT resources also consist of dedicated people with the vision and determination to continually push the state-of-the-art technologies for HWIL and distributed testing. Numerous scientists and engineers from the Munitions Directorate and its contractor support base have dedicated their lives to making the AGWT a national asset. ❑

CRAIG M. EWING graduated from The Ohio State University, Columbus, Ohio, in 1986 with a bachelor of science degree in aeronautical/astronautical engineering. He accepted a job with the United States Air Force civil service at Eglin Air Force Base, Florida, where he worked on guidance, navigation, and control issues for the Strategic Defense Initiative for 7 years, specializing in the area of guidance and estimation. While working at Eglin, he enrolled at the University of Florida Graduate Engineering Research Center to pursue a master's degree. He received a master of science degree in aerospace engineering in 1992 and a doctor of philosophy degree in engineering mechanics in 1999, both from the University of Florida. In 1994, he was assigned to the Air Force Research Laboratory (AFRL) Munitions Directorate team working to analyze advanced concepts at engagement and mission levels. He then accepted a position as the technical advisor for the Integrated Guidance Simulation Branch specializing in HWIL and synthetic scene generation for advanced munitions. He is currently the technical advisor for the Planning & Assessment Division at the AFRL Munitions Directorate, whose responsibilities include strategic planning and simulation-based acquisition using lethality & vulnerability assessment, computational mechanics analysis, and engagement and mission level analysis for the Air Force. E-mail: craig.ewing@eglin.af.mil

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