

Infrared System Test and Evaluation at APL

Scott A. Gearhart and Kathryn K. Vogel

The Applied Physics Laboratory's legacy in radar systems dates back to World War II. By comparison, experience in infrared (IR) technology is quite recent, beginning at a low level in the 1970s and escalating in the 1980s. Interest in IR systems for naval area defense applications was prompted by the increasing sophistication of air threats and the potential benefit of rapid advances in IR technology. Today, a large portion of the Laboratory's Navy mission work is IR systems. This article discusses the evolution and highlights of IR systems engineering, test, and evaluation capabilities at the Laboratory.

(Keywords: Hardware-in-the-loop, Infrared, Seeker, Test facilities.)

INTRODUCTION

Infrared (IR) sensors have long played an important role in our country's defense in diverse applications such as surveillance and early warning, aircraft and ground night-vision systems, and missile guidance. The Laboratory's earliest exposure to IR sensors occurred about 1969 with several small-scale tasks associated with the High-Energy Laser Program, the Coherent Laser Radar Program, and the Rolling Airframe Missile Program. It was not until about 1980, however, that interest and efforts in IR systems work expanded. In the mid-1970s, threats against our surface ships were becoming increasingly sophisticated, particularly in the area of radar jamming. A few visionaries at APL and elsewhere speculated that a combination of radar and IR guidance on a single defense missile would result in a significant tactical advantage. These queries into "dual-mode" guidance solutions spawned several feasibility studies, of which the most significant were the Wide-Area Guidance and Control Program, conducted from 1977 to 1983, and an advanced Standard Missile study conducted from 1980 to 1982.

In anticipation of the important role for IR systems in advanced guidance applications, APL began to

accumulate expertise in IR systems and their test and evaluation. Much of the existing test equipment was antiquated. Procurement and development of new test equipment proceeded slowly over several years (see Fig. 1). During this period, interest in dual-mode guidance systems grew slowly but steadily throughout the naval defense community. Once a clear need was established, the early exploratory preparations were instrumental in APL's rapid response in developing state-of-the-art IR system evaluation tools and test assets.

Today, through a period of phenomenal growth over the last decade, APL's expertise in IR systems rivals that found anywhere. Figure 2 shows the growth of IR-related activities that now include dual-mode IR and RF test and evaluation facilities, modeling and simulation capabilities, field data collection systems, laboratories for characterizing and modeling IR optical materials, and an aerothermal wind tunnel test facility. This article discusses the evolution and highlights of IR systems engineering, test, and evaluation capabilities at the Laboratory. It begins with advances in IR systems and their increasingly more stringent test requirements, and APL's test and evaluation philosophy,

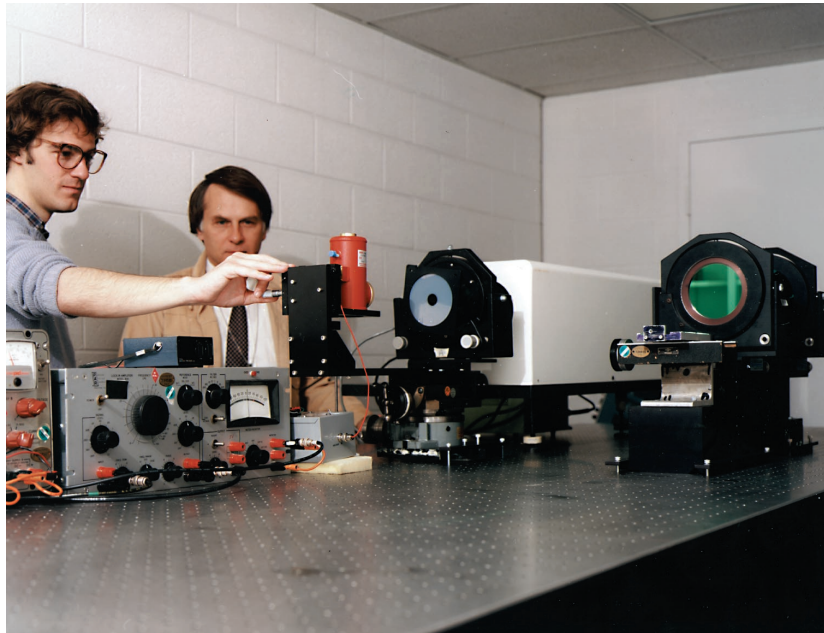


Figure 1. Terry Harris and Randy Bruns conducting measurements on IR components in the early 1980s.

which developed in response to these rapid advances. The article then summarizes the more innovative and significant APL test and evaluation accomplishments, and unique Laboratory test facilities. It concludes with future test needs and how the Laboratory is preparing to meet them.

ADVANCES IN IR GUIDANCE SYSTEMS

The earliest IR systems application, beginning in the 1950s, was guidance of air-to-air and ground-to-air defense missiles. These early systems had single-element IR detectors, which were either optically or mechanically scanned to track targets, and used a man-in-the-loop for target identification and designation. Defense systems using this technology have proven effective and are still in operation today. Advances in the late 1960s through the 1970s included forward-looking IR systems, most of which used a linear array of IR detectors and scanning mirrors to produce an image for a human observer. These systems are still used extensively on manned aircraft to facilitate nighttime operations. Similar technology is used for search and track systems. The latest revolution, which began in the late 1970s, is IR focal plane arrays, which use a two-dimensional array of IR detectors, imaging optics, a cryogenic cooling system, and readout electronics to produce an image. These devices are the culmination of years of advances in IR detector technology and only became commercially available about 1988. The use of

IR focal plane arrays in defense missiles is currently the cutting edge of technology.

Applications of IR systems on long-range and high-speed air defense missiles pose new technical challenges. Unlike earlier man-in-the-loop systems, more recent applications require the guidance system to autonomously acquire and track targets. Other autonomous functions include discriminating targets from natural backgrounds, debris, and IR countermeasures, as well as multiple-track processing and smart aimpoint selection. The greater detection sensitivity of these systems also increases clutter-induced false alarms that must be screened with sophisticated processors and algorithms. In addition, longer missile flight times, higher intercept altitudes, and higher ac-

celerations have placed more stringent requirements on the inertial stabilization unit. Perhaps most significantly, high velocities result in aerothermal heating of the IR seeker's protective dome and its internal components, which not only can degrade performance, but if not adequately protected, can cause catastrophic failure. Indeed, some new systems require ejectable covers and active cooling (i.e., the flow of a coolant) over the IR dome to survive the extreme flight environments.

To meet these advanced requirements, IR guidance systems are becoming increasingly complex and thus can no longer be treated independently. A modern IR guidance unit is a system composed of optics, a detector unit, a cryogenics supply, an inertially stabilized platform, power and control electronics, and a data processor. In turn, the IR guidance unit is part of a larger system, namely, the missile, which includes the autopilot, the missile inertial reference unit, the uplink and downlink receivers, and auxiliary guidance units (e.g., radar). Given this complexity, and new possibilities for data and sensor fusion, the IR systems engineer needs to have knowledge of the missile system as a whole.

The advances in IR technology, the increase in performance requirements, and the complexity of modern guidance systems have made devising tests and test facilities for evaluating these systems challenging. For example, applications that required simple stationary targets for testing are being replaced by those that require highly structured and dynamic IR environments. In some respects, the technical problems that

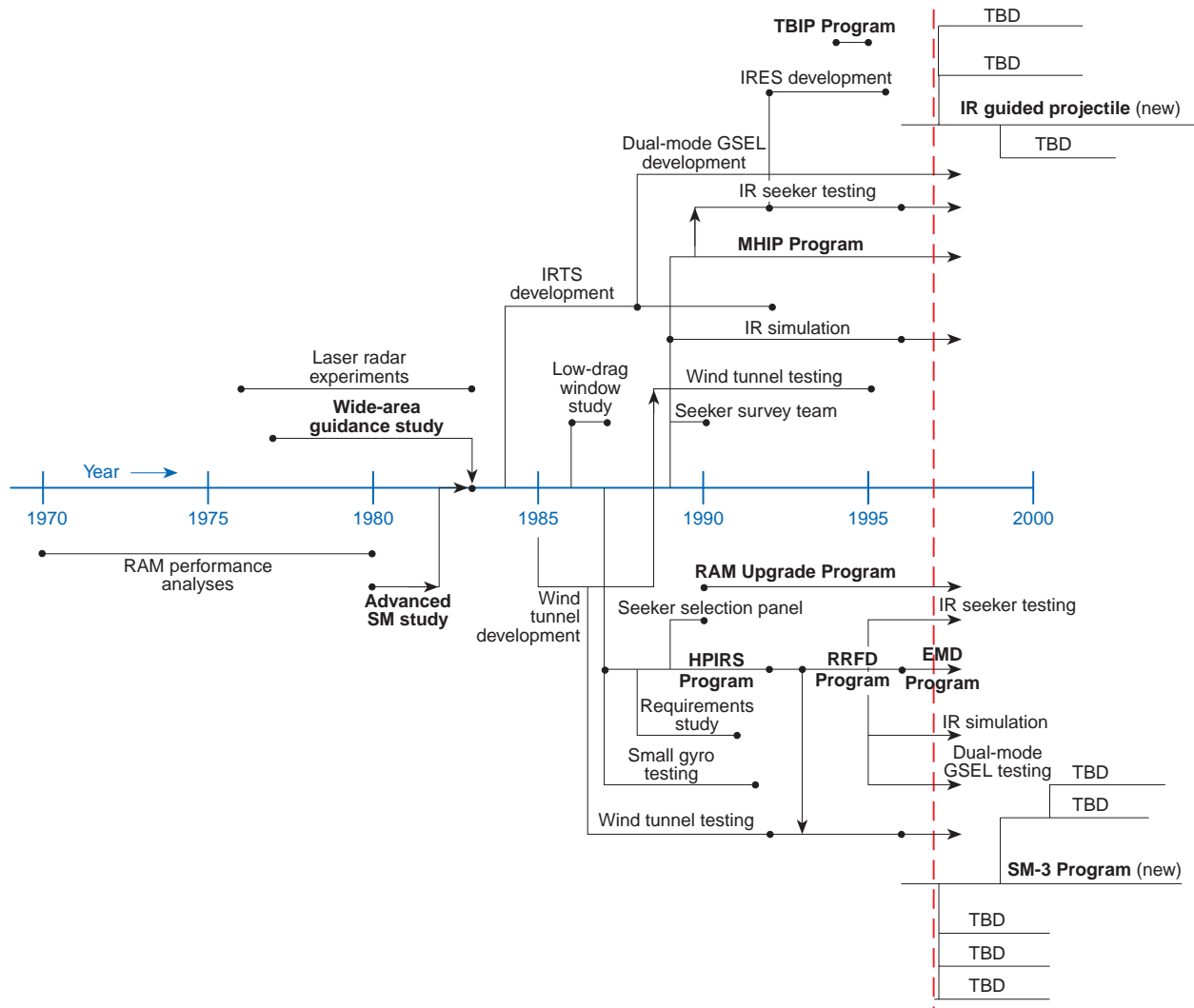


Figure 2. The evolution of IR-related activities at APL. (EMD = engineering and manufacturing development, GSEL = Guidance System Evaluation Laboratory, HPIRS = high-performance IR seeker, IRES = IR environment simulator, IRTS = IR target simulator, MHIP = Missile Homing Improvement Program, RAM = rolling airframe missile, RRFD = risk reduction flight demonstration, SM = Standard Missile, TBD = to be determined.)

must be solved to address these test issues rival those associated with developing the IR systems themselves. What is often overlooked is that advances in almost any technology proceed only in pace with advances in test and evaluation technology; otherwise, the critical empirical data required to develop a new approach are lacking.

APL'S TEST AND EVALUATION PHILOSOPHY

APL's philosophy for IR test and evaluation has been molded not only by hands-on experience with IR systems, but has evolved from a corporate "systems" legacy that precedes APL's IR-related work. Some attributes of this philosophy are delineated as follows:

1. *Aid in system development.* Perform tests to verify system functionality and collect critical data necessary to system hardware and algorithm development.
2. *Test incrementally.* Perform tests first to characterize performance at the subsystem level (e.g., the IR seeker or inertial stabilization unit levels). Tests of multiple subsystems and their interactions are based on experience gained at the subsystem level. A common tendency is to begin testing at too high a level of complexity (i.e., attempting a total end-to-end system test first). Problems seen at this high level of testing are difficult to isolate.
3. *Isolate problems and find solutions.* Detect and isolate problems in the system to reduce risk of failure in a costly missile flight test. Ensure the system meets its tactical requirements. Collaborate with the defense contractor in defining and validating solutions.

4. *Probe the system for vulnerabilities.* Devise tests that realistically stress the system. These are tests beyond the acceptance tests performed by the defense contractor at the factory.
5. *Combine test and simulation activities.* Use digital simulations where appropriate to study IR guidance and missile systems and their interactions. Simulations are essential in gauging system performance over the many scenarios and combinations of conditions that would be impractical to test. APL integrates simulation development and test programs. Simulation models are typically validated through testing as they are developed. Test data are used as inputs to define model parameters.
6. *Provide rapid response and timely documentation.* Respond quickly in investigating unexpected problems and devising solutions. APL has a reputation for devising difficult tests quickly that, although often lacking elegance, provide timely and essential information to our sponsors. Test results and analyses are typically documented, either in the form of a report or a formal presentation, within a few weeks.
7. *Avoid using the system to test itself.* (This expression was coined by APL's Tom Rankin and is now often referred to as "Rankin's law.") Although appearing to be an oxymoron, using measurements from the unit under test to gauge its own performance is a common practice. Such measurements might include gimbal angle, search rate, and target intensity readouts. Unfortunately, there have been cases where these data were erroneous, leading to false test results and conclusions. Before such data are relied on during tests, it is standard practice at APL to validate the data using external calibration devices.
8. *Develop test facilities that emphasize flexibility, portability, and growth.* Performance compromises should not be made in the test equipment to accommodate potential applications that might come later. Construct test equipment into modular building blocks that can be reconfigured, modified, or upgraded piecemeal as necessary. Provide flexibility for incremental testing. Design growth features, if possible.

Experience has shown that building general-purpose facilities suitable for testing all IR systems is extremely difficult and costly. Indeed, a test facility could be so complex that by the time it is in operation, its need has passed. Conversely, a test facility might be so specific to a particular system that it is useless for testing anything else. APL's test facility development efforts have attempted to reach a compromise between these two extremes.

HIGHLIGHTS OF TEST ACTIVITIES

The following highlights of APL's IR test activities were selected in part because of their significance to their respective Navy programs. In addition, several of the tests demonstrate a particular aspect of APL's test philosophy and have never been performed elsewhere. The seven tests described address issues of IR seeker search pattern stabilization, effects of ejecting the seeker protective cover during flight, seeker stabilization at high acceleration levels, operation in an extreme aerothermal heating environment, degradations caused by heating of seeker internal components, effects of rapid dome heating, and performance against IR countermeasures. In addition to the tests described, APL has performed numerous other tests including IR seeker gyro tests, missile roll dither tests, rooftop tests, flight-test support activities, seeker field tests, and dome survival tests.

Search Pattern Stabilization During Missile Roll

IR seekers typically execute a search pattern to acquire targets over large fields of regard. Some IR seekers do not have a roll-stabilized gimbal to keep the search pattern properly oriented during missile roll maneuvers. In this case, either the search pattern needs to be electronically de-rolled in image processing, or the azimuth and elevation gimbal search commands have to be actively roll compensated.

APL developed the apparatus and methodology to perform search pattern measurements in a roll environment for one IR seeker application. Figure 3 shows the mechanized roll fixture that holds the seeker and simulates missile roll transients. The roll fixture is instrumented to generate roll signals identical to those that would be produced by the missile inertial sensors. These roll data are injected into the seeker processor at the appropriate data rates. The roll data are required for the seeker roll compensation algorithms.

Instrumentation was devised to measure seeker search pattern accuracy during roll. A laser beam was reflected from the seeker primary mirror onto a diffuse transparent screen. A lens imaged the laser spot viewed through the back of the screen onto a position sensing detector. In this way, the laser traced the search pattern onto the position sensing detector.

These tests identified implementation errors in the roll compensation algorithms that were remedied. The laser measurement instrumentation was also key in identifying and quantifying gyro control-loop degradations and problems with the gyro nutation damper. The seeker supplier subsequently adopted the same

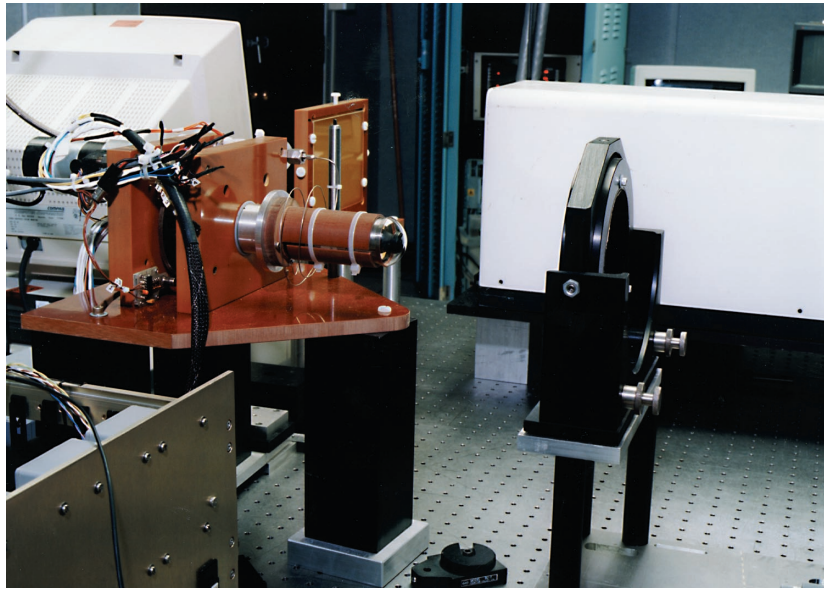


Figure 3. Mechanized roll fixture used in search pattern fidelity tests. The roll position readout was input to the seeker processor to emulate missile inertial measurement data.

instrumentation and test procedures for developmental testing.

Cover Removal Transients

Testing revealed that a small free-gyro-stabilized IR seeker might suffer significant transients in both spin speed and reported gimbal angle upon ejection of its protective steel cover during flight. Transients observed in tests where the cover was removed by hand persisted for a notable time, raising concerns about in-flight performance degradations. To accurately measure these transients, APL constructed a unique apparatus to emulate in-flight cover ejection. The test apparatus was designed to allow for controlled cover removal in less than 20 ms without damaging the seeker or cover.

Figure 4 shows the cover ejection apparatus. The seeker and cover mounting structure are rigidly attached to a base plate. The cover is placed in position over the seeker via the aft hinge and locked into position. Rather than using pyrotechnics to blow off the cover, a series of aircraft bungee cords were attached to the forward end of the cover and stretched, using a winch mechanism to provide a representative aerodynamic cover removal force and the desired cover removal time. An impact-absorbing shield was placed in back of the seeker/cover assembly to prevent damage to the components. A simple hand-operated mechanism released the cover.

Tests were conducted to measure gyro spin speed and gimbal angle readout transients during cover removal. The results showed that removal of the steel cover can indeed cause transients in seeker pointing that can

significantly delay the IR search process. Simulation models were updated to reflect these time delays, and solutions for the cover transient problem were recommended. The simple approach used for the cover removal apparatus led to a rapid understanding of the problem and, hence, possible solutions.

g-Sensitive Drift Tests Using a Linear Acceleration Sled

High accelerations (g) of advanced missiles impose demanding g -sensitive drift requirements on inertial platforms. This situation was of particular concern for one seeker application that used compensation algorithms to negate drift at high g levels. Constants used in the compensation algorithm were derived from empirical measurements made in a 1- g laboratory environment, and there was concern whether the compensation terms could be linearly extrapolated to higher g levels. In addition, even if appropriate, it was unclear whether

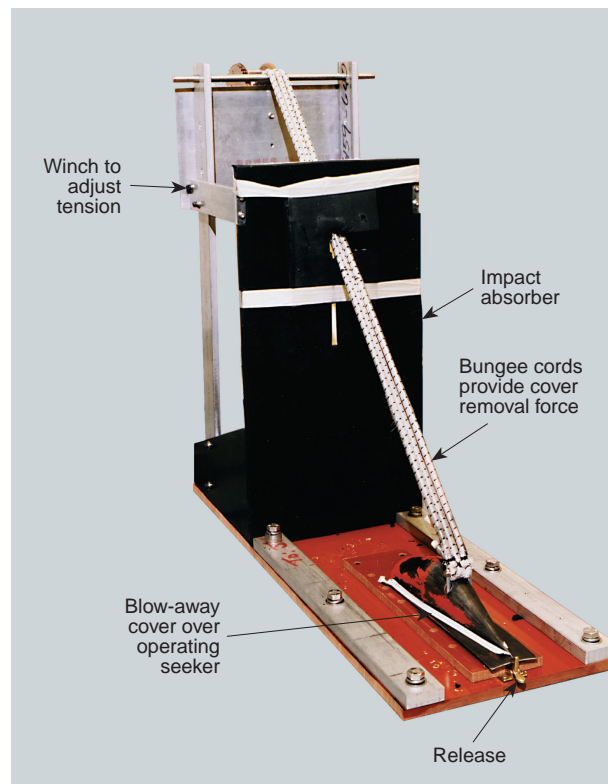


Figure 4. Apparatus to eject the seeker's protective cover.

1-g tests in the laboratory were sensitive enough to ensure that the algorithms were properly implemented. To measure seeker drift at higher accelerations, APL designed and built a servo-controlled linear acceleration sled, which was used to test the seeker against sinusoidal accelerations with amplitudes up to ± 4 g.

The sled is shown in Fig. 5 along with the IR seeker, control electronics, and various other support equipment. The sled track is approximately 10 ft long with the total travel of the seeker approaching 5 ft. The seeker is mounted on the sled so that its longitudinal axis is perpendicular to the acceleration input. The sled was located on the roof of a five-story building. While accelerated, the seeker was commanded to track a stationary target (an industrial-sized heater) approximately 3 mi away, and gyro drift data were recorded. Results from the sled tests verified the seeker supplier's g-sensitive drift measurements and compensation methodology.

Aerothermal Testing of an IR Seeker

An IR seeker was tested at APL's W. H. Avery Advanced Technology Development Laboratory in the Cell 4 wind tunnel. Cell 4 produces supersonic flow at the temperatures and pressures required for aerodynamic heating representative of missile flight. (A later section of the article provides a description of the Cell 4 wind tunnel.) The tests evaluated seeker performance in a hostile thermal, vibration, and electrical environment before flight testing. The specific test objectives

were first to collect IR detector waveforms to investigate scan modulation, a phenomenon that can greatly limit target acquisition performance in free-gyro seekers. (Scan modulation will be described in the following section.) A second objective was to transition the seeker through a preprogrammed functional sequence to demonstrate basic functionality. Finally, a test target was optically relayed into the wind tunnel for the seeker to attempt acquisition and track.

Operating an IR seeker in a supersonic aerothermal environment was a significant first. The tests proved that the seeker could survive and function in a severe flight-like environment. In addition, for the first time, scan modulation data were collected for a real aerodynamically heated dome. As a result, a new potential source for scan modulation was discovered, which provided the impetus for further study, including tests of instrumented seekers to measure internal temperatures.

Laser Heating of Components in a Free-Gyro IR Seeker

The distinguishing feature of a free-gyro IR seeker is the optical train spun at a high rate to produce the gyroscopic action for stabilization. As mentioned previously, one performance degradation mechanism of free-gyro IR seekers is scan modulation, which refers to signal artifacts superimposed on the detector voltage outputs associated with the spinning gyro. In past IR seeker applications, scan modulation was primarily attributable to electromagnetic pickup. In advanced applications where extreme aerothermal heating is present, scan modulation is primarily an optical/stray-light phenomenon that can be orders of magnitude higher than the electromagnetic contribution.

The wind tunnel tests described in the preceding section revealed scan modulation higher than anticipated, suggesting that hot internal seeker components could be a leading contributor in addition to the hot dome. To isolate and quantify scan modulation contributions, tests were performed to selectively heat internal seeker components.¹ In one test configuration, an argon laser was used to selectively heat components within the seeker while it was operating, and scan modulation waveforms were recorded. Temperature data were recorded using a thermal imager. In another test configuration, a CO₂

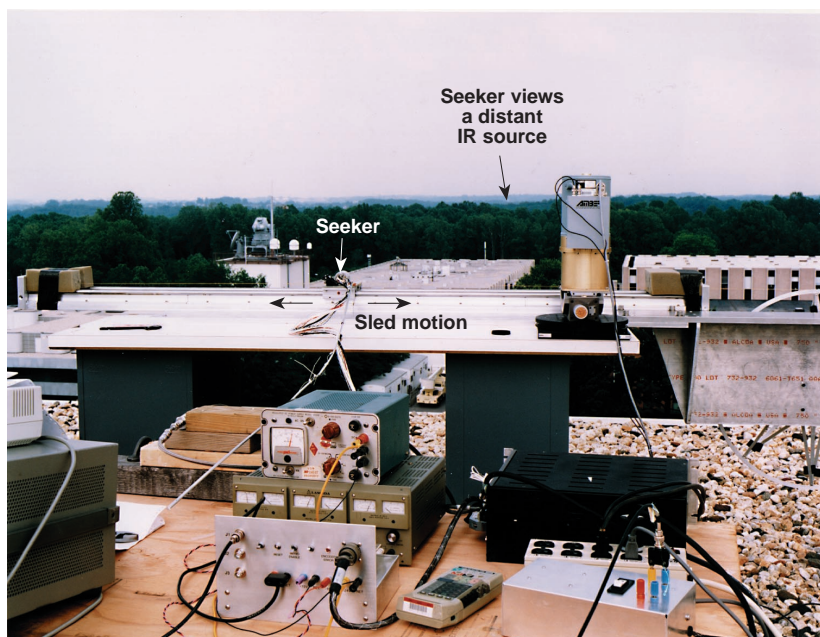


Figure 5. Seeker mounted on a linear acceleration sled used in *g*-sensitive drift measurements.

laser was used to heat the seeker dome while the seeker was operating, and temperatures of the internal components were monitored. Figure 6 shows a thermal image of the heated seeker components. The results of these tests indicated that the hot sunshade was potentially a major scan modulation source. In addition, the combined wind tunnel and laser heating tests suggested a convective heat transfer mechanism from dome to sunshade that was previously unknown.

Ramping Hot Dome Test

During high-speed missile flight, an IR dome rapidly reaches extremely high temperatures that can degrade seeker performance. One important performance consideration is dynamic range management. Dynamic range management algorithms (akin to automatic gain control) must be adequately responsive to prevent video saturation during rapid changes in dome background emission. Rapid heating also stresses the performance of focal plane array nonuniformity correction algorithms that compensate for pixel-to-pixel gain and offset variations. Finally, high dome emissions also increase photon noise, thereby affecting acquisition performance.

To assess these performance issues, APL devised a means of emulating the rapidly changing background flux associated with dome heating without the need for actually heating the dome. Background radiation from an extended-area blackbody source, representative of that produced by a hot dome, is combined with radiation from a test target using a beamsplitter (a partially coated mirror that is both transmissive and reflective), and the combined target and hot background are viewed by the seeker. The simulated dome radiation is ramped from low to high using a motorized attenuation device placed between the seeker and the extended-area blackbody. The dome heating profile and test target attributes are computer-controlled to represent

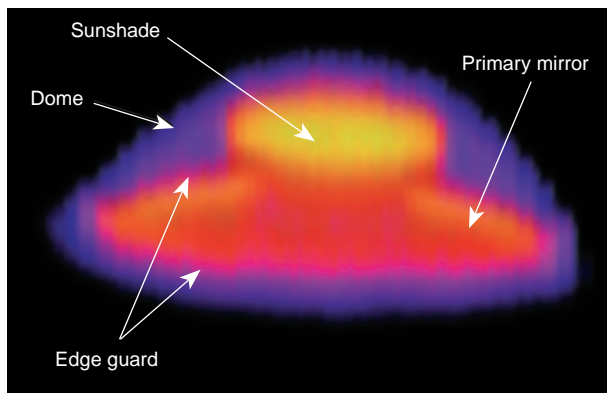


Figure 6. Thermal image of seeker free-gyro during dome heating with a CO₂ laser.

conditions predicted in dome tests and missile flight simulations. Results from a recent set of ramping hot dome tests were used for flight test mission planning.

Closed-Guidance Loop Tests of IR Counter-Countermeasures Algorithms

An important issue for most IR guidance systems is the susceptibility to IR countermeasures such as flares. Recently, hardware-in-the-loop (HIL) tests of a dual-mode RF/IR guidance system aimed at assessing performance in an IR countermeasures environment were conducted using APL's co-located dual-mode (IR/RF) Guidance System Evaluation Laboratory (GSEL) (described in the following section). In these tests, the IR seeker acquired and tracked an optically projected test target, and the missile guidance loop was closed. As described later, target motion was computer controlled to produce seeker-to-target line-of-sight angle rates commensurate with the combined motion of the target and missile intercept maneuvers. During terminal guidance, the test target ejected flare-like objects to assess the seeker's ability to maintain target track. The tests were repeated over an ensemble of flare separation and dispensing rates as well as several ejection geometries. These measurements have been the only ones taken to date that assessed the seeker's ability to reject flares in closed-loop guidance scenarios. The test results are providing a foundation for some new ideas to improve performance against countermeasures.

TEST FACILITIES AND CAPABILITIES

Dual-Mode (RF/IR) Guidance System Evaluation Laboratory

The dual-mode GSEL is a clear example of the Laboratory's philosophy of incremental and developmental testing, as well as modular and flexible test facilities (see the previous section on APL's test and evaluation philosophy). The dual-mode GSEL includes assets for benchtop seeker tests, individual IR- and RF-system HIL tests, and dual-mode (combined IR and RF) HIL guidance system tests. Several benchtop tests were described previously. This section emphasizes HIL testing.

HIL testing of a guidance system is often the final check of system functionality before missile flight tests. HIL testing of a guidance system typically involves connecting all the guidance system subassemblies, emulating ship and missile subsystem inputs, subjecting the RF and IR seekers to flight-representative target and background environments, and emulating an engagement scenario using a real-time flight simulation computer. At APL, the emphasis is on confirmation of interfaces, data transfers, subsystem interactions, and

functional sequences. The characteristics of the guidance system homing loop are also examined. In many cases, APL's HIL test program has identified subtle algorithm and software coding errors not detected at other levels of testing. Subtle anomalies like these, such as a missing negative sign in a coordinate transformation, can have costly consequences in a missile flight test.

A major challenge of dual-mode guidance system testing is adequately emulating both IR and RF flight environments. APL's early successes at dual-mode testing used an electrically connected configuration in which the missile RF guidance system was mounted in an anechoic chamber in front of an array of horns that simulated the target radar return, sea-surface clutter, and countermeasures. The IR seeker and its signal processor were removed from the guidance section and placed in a separate facility that optically projected the target and background images. The IR seeker processor was reconnected to the guidance section via a long transmission line. The HIL flight simulation computer synchronously controlled the RF and IR environment generators according to the engagement scenario.

Having the IR and RF seekers located in separate test locations affords one advantage—the test environments for each seeker can be more complex than what could be achieved with the two seekers integrated and tested in a common facility where space constraints are prohibitive. For example, in the electrically connected configuration, the IR seeker could be mounted on a rate or vibration table while environments are viewed

through an IR projector. In addition, in this configuration, there are no worries that the IR generation equipment might affect the fidelity of the RF simulation, and vice versa. For these reasons, the electrically connected configuration continues to be important for APL's HIL test activities, particularly for those aimed at system development. Clearly, however, the necessity of removing the IR seeker from the guidance system is invasive and not desirable for preflight checkout and production assurance testing. To provide an alternative configuration that precludes disassembly of the guidance system, the Laboratory constructed the co-located dual-mode IR/RF GSEL.^{2,3}

The co-located dual-mode IR/RF GSEL layout is shown in Fig. 7. The guidance system, including the IR seeker, is mounted in an anechoic chamber in front of an RF linear array. IR environments are generated outside the chamber and optically relayed to the interior. A periscope provides the optical interface to the IR seeker. As shown in the figure, the co-located dual-mode GSEL is designed for testing guidance systems with the RF seeker in the missile nose and the IR seeker mounted on the missile side.

The design challenges for the co-located dual-mode GSEL were numerous and included providing adequate vibration isolation as well as getting IR radiation into the anechoic chamber without RF leakage. The most difficult constraint was the limited-size envelope for the IR generation system, which greatly influenced the design approach. For example, IR relay optics inside the

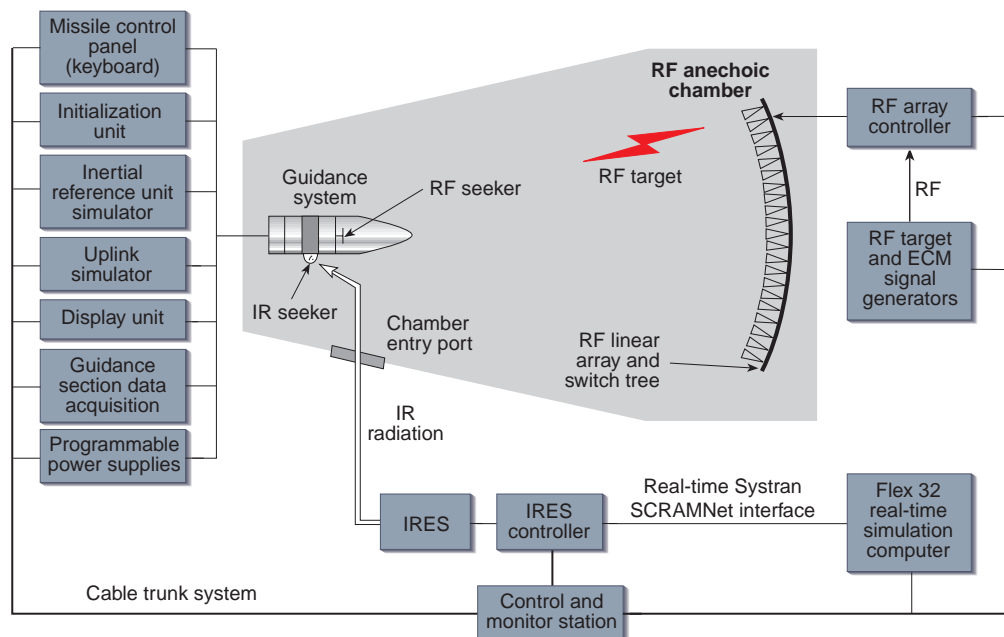


Figure 7. Co-located dual-mode hardware-in-the-loop test configuration. (IRES = IR environment simulator, ECM = electronic countermeasures.)

chamber were required to be behind the RF seeker antenna with an adequate margin for RF shielding, as well as fit in the space available below the guidance system. Conflicting with this requirement was the desire for flexibility in injecting the IR radiation into the IR seeker over a large angular range. Many design iterations were required to find a compromise between these requirements. In addition, the bulk of the IR generation equipment outside the chamber had to fit into a tight-size envelope to keep optical relay paths as short as possible. Analysis showed that longer paths would have greatly reduced the optical performance of the system. Providing a projection system that displays sufficiently complex environments and also fits into a tight-size envelope is perhaps the most ambitious optomechanical development task attempted at APL. Appropriately, the IR Environment Simulator (IRES) is the subject of the next section.

The IR Environment Simulator

The IRES is a computer-controlled optomechanical system that projects IR targets, backgrounds, and countermeasures. The chief design goal for the IRES was achieving good optical performance while maintaining compactness and modularity. As mentioned previously, compactness was a prime concern for application to the co-located dual-mode GSEL. Modularity was important because of the desire for a general-purpose test resource that could be moved and assembled in various configurations, including electrically connected HIL tests and seeker bench tests.

The starting point for the design of the IRES was the IR target simulator (IRTS) constructed in the mid-1980s. Although the IRTS served its intended function well, it was too large. Figure 8 shows that the IRTS, which projected a single moving target and a background scene, occupied a 4×12 ft optical bench. The IRES requirement was to use approximately the same

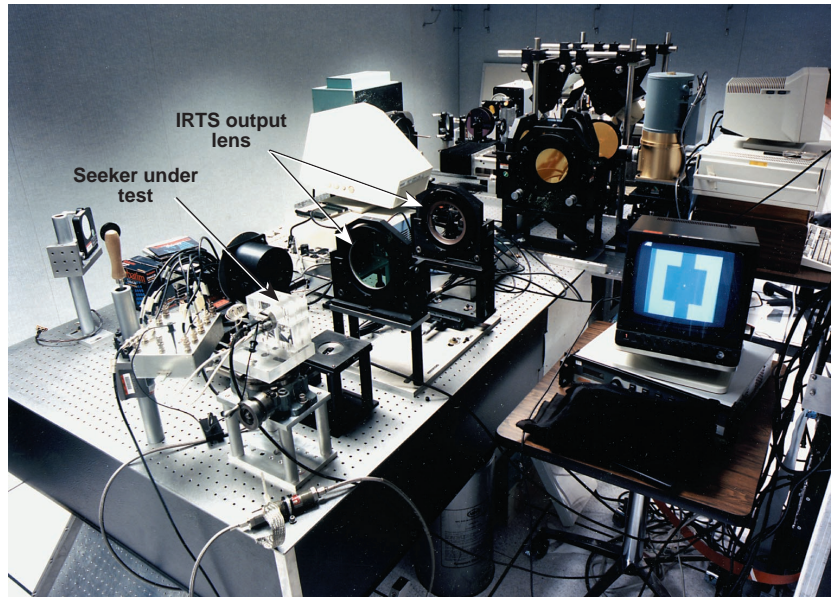


Figure 8. The IR target simulator (IRTS) developed in the mid-1980s. The IRTS occupies a 4×12 ft optical bench.

space used for two targets, the background scene, and a suite of relay optics. One key to minimizing the IRES size envelope was the use of small scanning mirrors as opposed to large linear slide tables used in the IRTS to move the targets. In addition, optical paths were folded and layered in two planes, and lens design was optimized to reduce component dimensions. Figure 9 shows the reduction in scale achieved for one IRES target generator. Here, several IRES modules are configured for benchtop seeker testing.

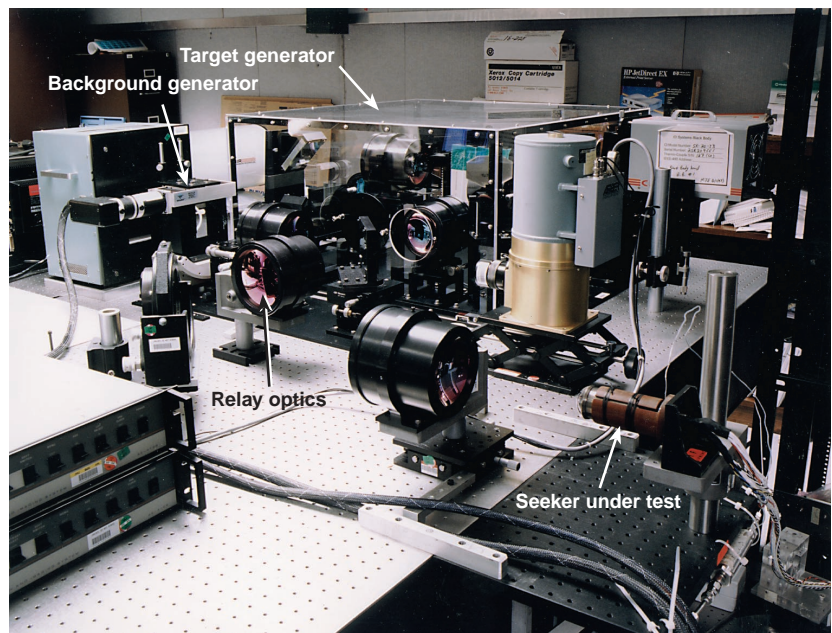


Figure 9. Seeker benchtop testing using the IR environment simulator (IRES) closing target and background generators.

Figure 10a shows the IRES fully configured for co-located GSEL testing. The prime components include a closing target generator, a point target/IR countermeasures generator, a static background scene generator, an optical relay module, and a periscope inside the anechoic chamber. Figure 10b shows the periscope mounted on a rotary table that allows IRES inputs to be injected into the seeker over a $\pm 45^\circ$ azimuthal range. Outputs from each component are combined with beamsplitters. The IRES is transmissive in the 3- to 5- μm wavelength band.

Materials and Spectroscopy Laboratory

Optical properties of materials are important in guidance system performance evaluation. For the past decade, APL has measured and modeled temperature-dependent optical properties of windows, coolant gases, and surfaces for use in calculating seeker performance, developing evaluation facilities, and setting test conditions. Measurements are made in the Materials and Spectroscopy Laboratory, which includes several spectrometers, lasers, test cells, vacuum systems, and data acquisition and processing capabilities for complete optical properties characterization as well as remote sensing and biomedical applications.

Seeker windows in high-speed missiles are exposed to considerable heating. Window thermal emission is a crucial factor that affects seeker noise, dynamic range, non-uniformity compensation, and scan modulation performance, as well as radiative heat transfer to internal seeker components. To characterize transparent materials, APL has developed techniques to measure temperature-dependent transmission⁴ (to infer emission at lower temperatures) and emission⁵ up to 2000 K. Other measurements supporting window characterization include the temperature dependence of the refractive index⁶ and scatter properties,⁷ particularly of polycrystalline materials. Measurements are incorporated in widely used optical property models,⁸ including the commercially available OPTIMATR software, and standard references.^{9,10}

Emission and reflectance properties of opaque materials are also measured and developed into angular- and frequency-dependent descriptions of optical properties. Such descriptions are used with aerodynamic, heat transfer, and geometric viewing to develop target signatures and own-missile self-emission models.

The W. H. Avery Advanced Technology Development Laboratory

The Avery Laboratory's Cell 4 wind tunnel is used for experimental

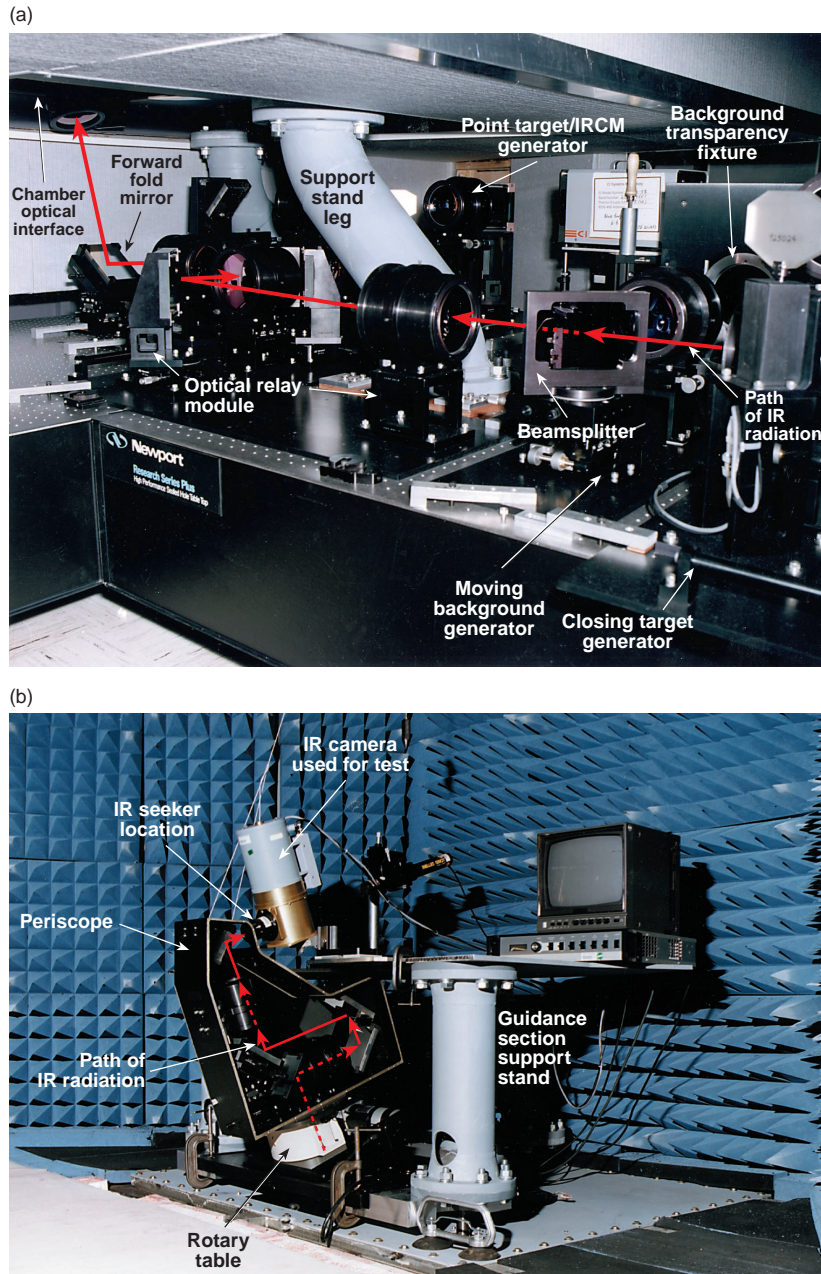


Figure 10. The IR environment simulator (IRES) configured for co-located dual-mode Guidance System Evaluation Laboratory testing. (a) The optics outside the anechoic chamber. (b) The periscope mounted on a rotary table. (IRCM = IR countermeasures.)

evaluation of IR seekers and components in high-energy flow fields representative of missile flight.¹¹ The principal components of the facility include a Mach 5 nozzle, a hydrogen combustion heater, a test cabin, and a downstream exhaust diffuser, which result in a 10-in.-dia. flow field that can be heated to temperatures as high as 2222 K. An injection unit allows IR components to be inserted into the airstream after flow conditions have been established. Several windows in the sides of the test chamber provide for access of collimated IR sources and cameras for optical measurements.

Cell 4 has been used to test IR seeker components in a natural progression: first domes, mounting materials, and blow-off covers; then seeker mock-ups; and finally real operating seekers. Significant accomplishments to date include investigations of thermal shock capabilities of IR dome materials, internal seeker temperatures and vibration, cover removal methodologies, IR dome cooling techniques, IR seeker survivability and functionality, IR seeker scan modulation, and aero-optical effects. So far, over 800 IR-related tests have been performed in Cell 4. Of these, about 150 tests were performed to examine dome-cooling performance alone. Figure 11 shows a seeker dome being tested in the wind tunnel.

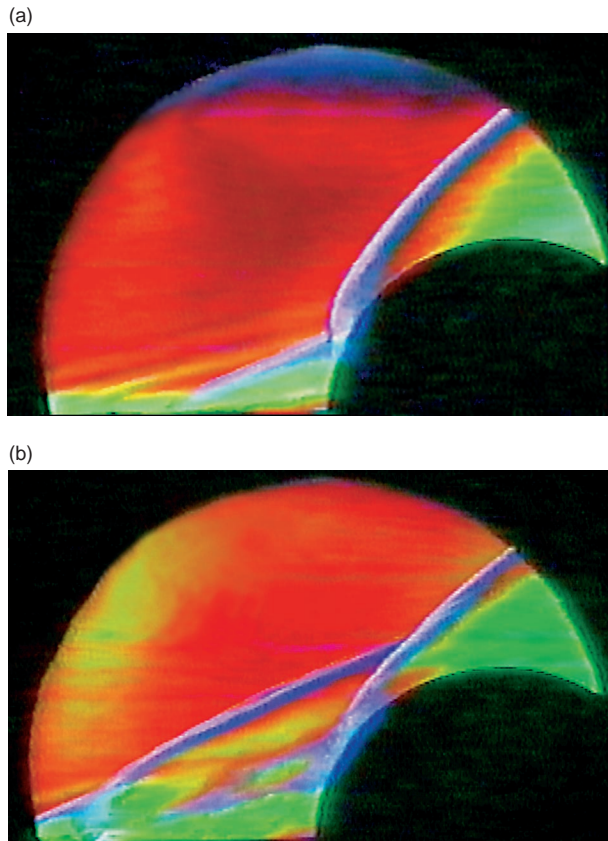


Figure 11. Dome-cooling tests in the W. H. Avery Advanced Technology Development Laboratory. (a) No cooling. (b) Helium forward cooling.

IR Image Data Acquisition and Analysis

APL has designed and configured a specialized camera system to collect radiometrically calibrated clutter data in the midwave band. In one application, IR measurements of the marine environment were taken to study infrared seeker performance, develop and test image-processing algorithms, statistically characterize clutter, and validate an APL-developed ocean clutter synthesis model. In other applications, the system was used for collecting IR imagery of ground structures and clutter to better understand diurnal and climatic variations.

The camera system consists of two portable instrument pallets. The first pallet includes a 256×256 Cincinnati Electronics focal plane array camera that operates in a variety of subbands in the 3- to $5\text{-}\mu\text{m}$ waveband. This camera and a commercial 8-mm video camera are mounted on a DC servo-driven elevation-over-azimuth pointing head. A local computer digitally controls the cameras and servos and collects image data. A second pallet is connected via local area network and video coaxial lines. Distributed signal- and image-processing software manages the automated data collection task, as well as displays and analyzes the data at the time of collection.

The compactness of this system allows for easy transportation and fast setup, and also meets small space requirements. Field test exercises initially included ocean clutter measurements from offshore and at sea. They have now been extended to missile and target signatures and desert clutter measurements.¹²

CONCLUSION

Even as test facilities are completed, more stringent test requirements arise. Constant reevaluation and upgrading of capabilities are needed in today's defense community environment. For example, recent IR systems applications will require highly structured and dynamic IR test environments. APL is well into the planning phase to develop the appropriate facilities to test these systems. Figure 12 shows an image from the newest innovation of IR test technology, the resistor array scene projector. APL is acquiring such a device in 1997.

APL does not develop facilities for the sake of testing; rather, we test to help develop systems for our sponsors. There are no dedicated test engineers. Often, the same personnel who perform design trades, develop simulations, and interact with the sponsors are the same ones who devise, conduct, analyze, and document the tests. Enough cannot be said for intimately understanding the system to be tested. This should always be our emphasis and priority.



Figure 12. An IR image projected with a resistive heater scene projector. (Photo provided courtesy of Alan Pritchard of British Aerospace's Sowerby Research Center.)

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THE AUTHORS



SCOTT A. GEARHART is a Principal Professional Staff engineer in the Electro-Optical Systems Group of the Air Defense Systems Department. He received a B.S. degree in engineering science from the Pennsylvania State University in 1982 and an M.S. degree in electrical engineering from The University of Maryland in 1987. Mr. Gearhart joined APL in 1983 and has worked primarily on the development and evaluation of optical and infrared sensors for guidance and surveillance applications. He has also participated in IR&D efforts in optical radar processing and laser remote sensing, as well as biomedical studies of laser angiography and laser Doppler velocimetry of simulated blood flow. His e-mail address is Scott.Gearhart@jhuapl.edu.



KATHRYN K. VOGEL is a Senior Professional Staff engineer in the Electro-Optical Systems Group of the Air Defense Systems Department. She received a B.S. degree from Drexel University in 1983 and an M.S. degree from The Johns Hopkins University in 1988, both in electrical engineering. Since joining APL in 1983, Ms. Vogel has worked on the test, evaluation, and simulation of infrared and inertial systems primarily for missile guidance. Her experience includes coordinating IR seeker test activities, analysis of laboratory and flight data, seeker performance evaluation, inertial component testing, and modeling and simulation of IR seeker dynamics and inertial systems. Currently, she is involved in the development of a terminal seeker for a gun-launched munition. Her e-mail address is Kathryn.Vogel@jhuapl.edu.