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AIRCRAFT SURVIVABILITY

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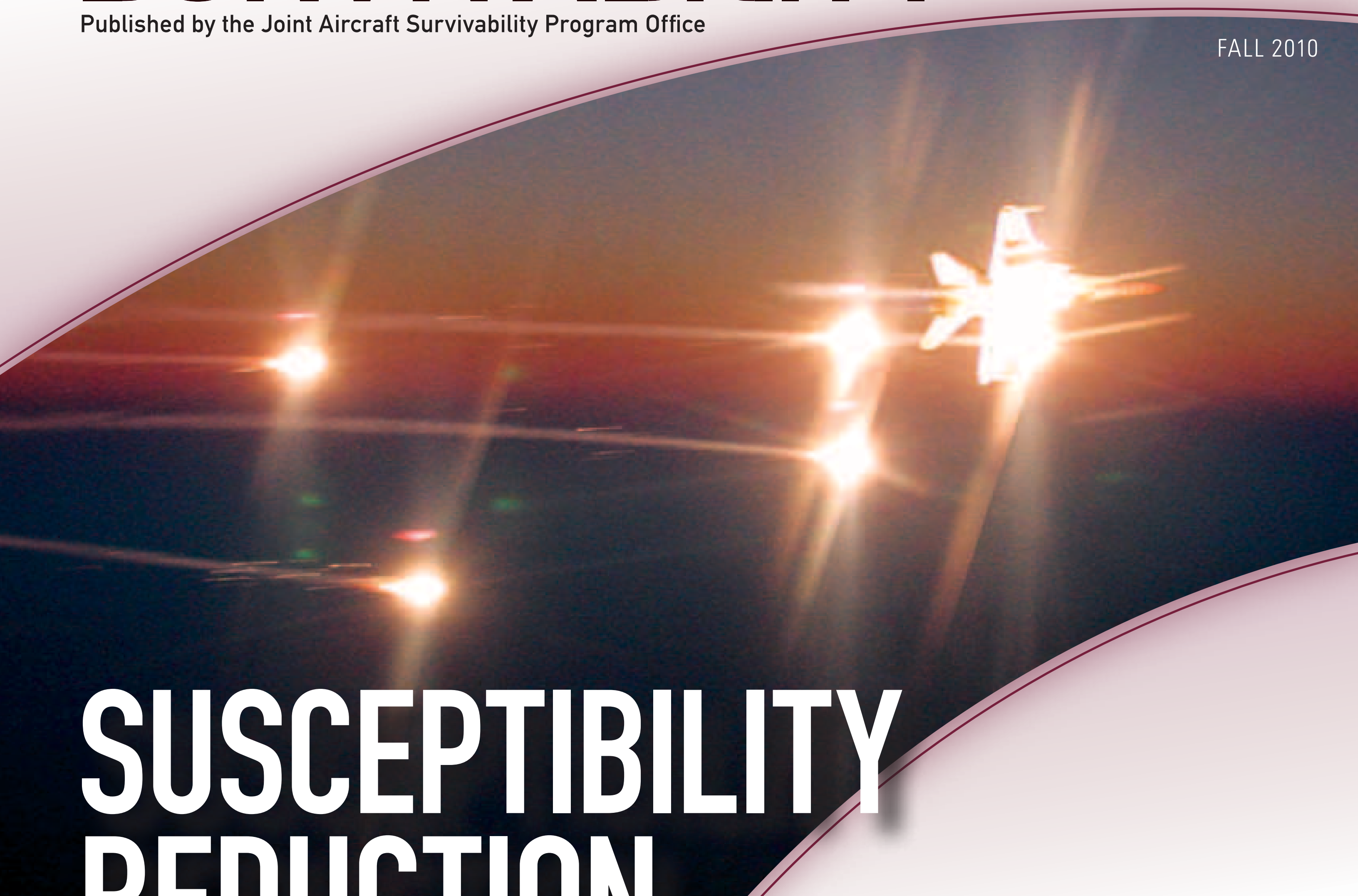

SUSCEPTIBILITY REDUCTION

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JAS Program Office
200 12th Street South
Crystal Gateway #4, Suite 1103
Arlington, VA 22202
Views and comments are welcome and may be addressed to the:

Editor
Dennis Lindell

Assistant Editor
Dale B. Atkinson

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On the cover:
An F/A-18C "Hornet" from the "Shrikes" of Strike Fighter Squadron Ninety-Four (VFA-94) fires off flares during a training mission. US Navy Photo by LT Steve Lightstone.

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According to Robert Ball, susceptibility reduction (SR), or threat avoidance, is achieved by reducing the probability that an aircraft will be detected, tracked, engaged, and hit. The Joint Aircraft Survivability Program (JASP) contributes to the susceptibility reduction of DoD aircraft through the efforts of the Susceptibility Reduction (SR) Technical Subgroup. The SR Subgroup is comprised of scientists and engineers from across the Services and DoD who are technical subject matter experts (SMEs) and leaders in their fields. Collectively, their mission is to advance existing SR capabilities and develop/assess technologies for advanced threats.

It is not hard these days to find a headline concerning a major defense program that has encountered significant cost overruns. The root cause of the cost overrun is often a shortfall in technology maturity that was not recognized before the program's start. The traditional acquisition approach limits flexibility when issues are encountered during development. Once a program enters Engineering, Manufacturing, and Development (EMD), the approach has often been to continue to work through any technical issues until they are resolved with the prime contractor. While cost and schedule overruns are painful, changing acquisition strategies in EMD can result in a program new start or the risk of program cancellation—thus delaying needed capabilities for the warfighter.

Defense Acquisition University courses encourage program managers to plan for sustainment "upfront and early." This becomes even more important when aircraft and systems stay operational for up to 50 years or more. The mission of the 542d is to deliver and sustain affordable, war-winning Electronic Warfare (EW) capabilities on time. That means keeping nearly 70 different EW systems with over 30 different software languages viable and effective in an ever-changing survivability environment.

Since 1980, Man-Portable Air Defense Systems (MANPADS) have been used to attack 35 civil aircraft worldwide, damaging 24 aircraft and claiming 500 lives. Because aviation contributes more than $3.5 trillion to the global economy, a successful MANPADS attack against a US commercial passenger aircraft could have catastrophic economic impacts extending far beyond the tragic loss of life. The United States and other concerned countries have recognized the implications that the proliferation of MANPADS represents to global economic and political stability, and have taken steps to counter this threat.

Mailing list additions, deletions, changes, and calendar items may be directed to:

SURVIAC

SURVIAC Satellite Office

13200 Woodland Park Road
Suite 6047
Herndon, VA 20171

Promotional Director
Jerri Limer

Creative Director
Jerri Limer

Art Director
Michelle DePrenger

Technical Editors
Kali Wilson

Newsletter Design
Tammy Black

Illustrations, Cover Design, Layout
Kacy Littlehale
Lacey Olivares

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by Dale Atkinson

NDIA UAS Self-Protection Workshop

If your interest lies in protecting our unmanned aerial systems (UAS) from hostile air defenses, the place to be on 27 May 2010 was the UAS Self-Protection Workshop co-hosted by the National Defense Industrial Association's (NDIA) Combat Survivability Division (CSD) and Director, Operational Test & Evaluation (DOT&E)/ Live Fire Test & Evaluation (LFT&E). Approximately 60 UAS and aircraft survivability equipment (ASE) subject matter experts from across the Department of Defense (DoD) and industry convened at the Institute for Defense Analyses (IDA) in Alexandria, VA, to develop recommendations for integrating combat survivability into UAS platforms with a focus on platform self-protection.

Mr. Michael Crisp, Deputy Director, Operational Test and Evaluation, Land Warfare and BG Stephen Mundt, USA (Ret), Chairman of the NDIA CSD delivered keynote addresses where they challenged the workshop to develop practicable, cost-effective means to address workshop issues—

- *Is there a problem?*
- *What are the issues in putting ASE on UAS platforms?*
- *Where should we invest our RDT&E dollars?*

To facilitate discussions, with the realization there will be different recommendations for different types of UAS platforms, the workshop was divided into three workgroups based on UAS platform performance and size. Each workgroup was led by a moderator/chair who focused the group to address workshop issues and obtain consensus on its recommendations. To help the groups get started, invited presentations on UAS-related threat intelligence and Service/program updates were gracefully delivered by NGIC, MISC, NASIC, ACC, NAVAIR PMA-272, and the NAVAIR Combat Survivability Division.

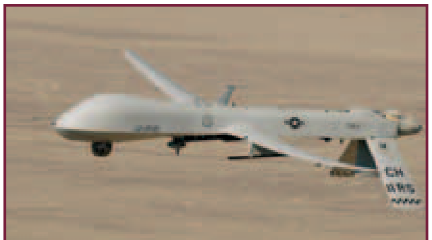

Photo Credit: USAF, MSgt Scott Reed

The workshop's ultimate output will be a short summary report documenting its findings and recommendations, which will be delivered to key leaders in industry and the DoD.

Dennis Lindell Wins 2009 NDIA OSD Civilian Tester of the Year Award

Mr. Dennis Lindell was recognized as 2009 Civilian Tester of the Year, Office of the Secretary of Defense (OSD) category, by the National Defense Industrial Association (NDIA) at its annual test and evaluation conference in San Diego, CA, on 3 March, 2010. This award is presented annually to outstanding individuals in the field of testing and evaluation, with the test and evaluation departments of OSD and each military Service each selecting three award recipients (military, civilian, and contractor) to be recognized as Testers of the Year.

As Program Manager of the Joint Aircraft Survivability Program (JASP), Mr. Lindell demonstrated outstanding leadership in completing the Congressionally mandated Study on Rotorcraft Survivability. His expertise and willingness to lead this study resulted in a significant achievement in the analysis and documentation of helicopter survivability data. Mr. Lindell's skillful management of the JASP and its numerous test and demonstration initiatives uniquely positioned him to lead the study in its focus on authoritatively recommending readily deployable survivability initiatives vital to the warfighter.

Mr. Dennis Lindell receives the OSD 2009 Civilian Tester of the Year award from Mr. David Duma, Principal Deputy, DOT&E at NDIA's Test and Evaluation Conference in March 2010

Mr. Lindell led the study effort given little guidance, no additional funding, and limited time to perform. In less than a year, he rallied the necessary contributors, focused their efforts, drafted the report, obtained coordination across the Services, and reported results to the Undersecretary of Defense, Acquisition, Technology, and Logistics [USD(AT&L)] and the DOT&E. His leadership in the successful completion and delivery of this report to Congress, together with his subsequent presentation of its findings, has resulted in a greater emphasis on rotorcraft survivability throughout the DoD and industry—leading to reduced losses for our warfighters.

This award for outstanding performance acknowledges the exceptional leadership and visionary contributions of Mr. Lindell to test and evaluation, the armed forces, and our nation. Congratulations, Dennis on a job well done!

Walt Dotseth Wins 2010 AIAA Survivability Award

Congratulations to Mr. Walt Dotseth as the 2010 recipient of the AIAA Survivability Award. The bi-annual award is presented to an individual or team to recognize outstanding achievement or contribution in the design, analysis, implementation, and/or education of survivability in an aerospace system. The award was presented to Mr. Dotseth by Kathleen Atkins, Director of the AIAA Aerospace

Design and Structures Group, at the AIAA annual awards luncheon held on 14 April 2010 in Orlando, FL.

Mr. Dotseth was recognized for his exceptional contributions during a long career of performing and promoting both nuclear and non-nuclear aircraft survivability design and enhancement, including major accomplishments that were a direct result of his leadership, creativity, and educational awareness. As a respected member of the survivability community since the early 1960s, Mr. Dotseth was one of the original proponents for establishing survivability as an integrated design discipline.

Mr. Dotseth's technical achievements are noted in the survivability design for many aircraft, including the B-1 and B-2 bombers. He was responsible for low observable signature analyses, hostile threat assessments, nuclear weapon delivery analyses, surface-to-air missile encounters, and compliance of nuclear hardness requirements. He can be credited for developing the first *Aeronautical Survivability Design Handbook* in the late 1960s, which formed the basis of MIL-HDBK-336. In addition, Mr. Dotseth played a key role in the development of the Navy *Aeronautical Requirement for Systems Survivability*, AR-107, which later served as the basis for DoD MIL-STD-2069. In addition to direct survivability support, Mr. Dotseth also supported the aircraft battle damage assessment and repair discipline by combining his knowledge of threats and damage with his structural repair experience.

Mr. Dotseth has had a profound influence on the ability of the Department of Defense survivability community and its industry counterparts to provide effective, survivable combat aircraft to our fighting forces. Congratulations on receiving the AIAA 2010 Survivability Award, Walt.

Updated Vulnerability Toolkit Now Available

The Survivability/Vulnerability Information Analysis Center (SURVIAC) has begun distributing the newest version of its Vulnerability Toolkit. These programs and their upgrades were funded by the Joint Aircraft Survivability Program Office (JASPO) and developed by the Aeronautical Systems Center (ASC)/ENDA.

The new version includes improvements to the Computation of Vulnerable Area Tool (COVART), the Fast Shotline Generator (FASTGEN), the Projectile Penetration library (ProjPen), and VulnView.

COVART 6.1.1: The Computation of Vulnerable Area Tool (COVART) computer program is a method for determining the vulnerable areas of targets damaged by impacting single kinetic-energy (KE) penetrators, shaped charge jet penetrators (SCJ), and high-explosive (HE) threats (including MANPADS and proximity-fuzed warheads). COVART 6 supports both FASTGEN and BRL-CAD targets in their native formats, and runs on Microsoft Windows and Linux operating systems.

Features added in COVART 6.1.1 include—

- Improved memory management
- Support for radially asymmetric (*i.e.*, directional) warheads
- Ability to assess cumulative effects of multiple threat impacts on a component
- Ability to reuse shotline data generated in Integrated mode
- Updated FASTGEN ray tracing library
  - FASTGEN 6.1 includes the addition of curved CLINE elements (CELBOW)
- Updated ProjPen projectile penetration equation library
  - ProjPen 2.3 includes updates to support interface with the Advanced Joint Effectiveness Module (AJEM)

The following loadable libraries are included with COVART 6.1.1 in addition to the main COVART program—

- Ray tracing
  - FASTGEN 6.1
  - BRL-CAD 7.12.4
- Penetration
  - ProjPen 2.3 (projectiles)
  - FATEPEN 3.2.18.1 (fragments)
  - FragPen (JTCG/ME Fragment Penetration Equations)
  - SCJ (Fireman-Pugh shaped charge jet methodology)
- Damage
- Fault tree

VulnView 3.2: VulnView is a Microsoft Windows-based viewer developed by ASC/XRE for FASTGEN4, Shazam3, and STL geometry files. It also supports display of PkPlot data output from COVART and geometry colormapping files. It can be used as the Combat Assessment Tool (CAT), which can model target damage patterns from known threat characteristics and threat orientation relative to the target.

Features added to VulnView 3.2 include—

- Ability to draw multiple lines and line segments from within the viewer
- Additional mouse controls (pan, rotate, and zoom)
- Colormap file support
- Additional input file control for CAT mode
- Use of JTYPE file for additional display options
- Ability to export modified CBULK files
- Support for FASTGEN CELBOW elements

You can obtain the new version of the Vulnerability Toolkit from SURVIAC.

New ALARM 5.4 and EARCE 3.4 Models Now Available

SURVIAC has begun distributing the newest versions of both the Advanced Low Altitude Radar Model (ALARM)—version 5.4, an upgrade from ALARM 5.2—and the ESAMS, ALARM, and RADGUNS (EAR) Common RF Environment (CE) (EARCE)—version 3.4—with documentation.

ALARM 5.4

ALARM is a generic digital computer simulation designed to evaluate the performance of a ground-based radar system attempting to detect low-altitude aircraft. It is intended to provide the radar analyst with a software simulation tool to evaluate system detection performance against the target of interest in a realistic environment. ALARM can simulate pulsed/Moving

Target Indicator (MTI) and Pulse Doppler (PD)-type radar systems, with a limited capability to model continuous wave (CW) radar. Radar detection calculations are based on the signal-to-noise (S/N) radar range equations commonly used in radar analysis.

ALARM offers four simulation modes—Flight Path Analysis (FPA), Horizontal Detection Contour (HDC), Vertical Coverage Envelope (VCE), and Vertical Detection Contour (VDC).

ALARM 5.4 is an enhancement release with several changes. Here is a list of the new ALARM inputs: VPDRCS_FILE, CLUT_ZONE_TABLE.

Changes in the newest release include—

- Added a new RCS file type named VPDRCS. This file type contains a processed RCS value that is dependent on target velocity and radar probability of detection. (SPCR #1387)
- Added support for FPA flight paths that are relative to the radar. (SPCR #1146)
- Fixed an access violation that occurred on Windows machines for a particular configuration of an input file. (SPCR #1389)
- Fixed an array-bound violation that could occur when using the _TABLE-type inputs. (SPCR #1392)
- Added a new support utility, RCSAntChart. This utility is for plotting antenna files and RCS files. (SPCR #1390)
- Fixed incorrect check of GPVAL_TERM in template files. (SPCR #1394)
- Fixed a problem with the create_a_contour script that caused it to fail for plot types "conlos" and "intlos." Also added a new option of "-S factor" to the S/I scale factor when applicable. (SPCR #1395)
- Fixed a divide-by-zero error that occurred when the target was below the terrain. (SPCR #1396)
- Fixed an issue where the last point of a 2D pattern was not being used. This problem was only an issue when an antenna pattern had a very small number of points. (SPCR #1376)
- Provided workaround for Sun Studio 9 failing to compile hdc_diary_class with optimization. (SPCR #1397)
- Fixed possible use of unallocated jam_list in detection_manager.f90. (SPCR #1399)
- Fixed an issue with the VCE controller when running multiple files. (SPCR #1401)

EARCE 3.4

The new version of the ESAMS, ALARM, and RADGUNS (EAR) Common RF Environment (CE) (EARCE) Modeling Component is an upgrade from EARCE 3.2. The EAR models comprise the core set used by the Joint Aircraft Survivability Program (JASP), whose methodology subgroup's mission is to establish an accepted joint service methodology for conducting air weapon survivability analysis using a flexible, efficient computational environment based on a credible set of components. Unfortunately, current survivability codes contain many duplicative algorithms on which model developers and the JASP have expended significant resources for development and validation. In an effort to eliminate these duplications, lower operating/validation costs, and provide more consistent results, the JASP has sponsored an effort to develop common RF modeling components for the EAR models as part of a Common Model Component Set (CMCS)—of which the CE is a part.

Changes made to EARCE and incorporated into ALARM include—

- Fixed the computation that bounded relative clutter angles to +/- p. (SPCR #1398)
- Added the ability to specify zones with differing clutter parameters. (SPCR #1391)

New versions of ALARM and EARCE may be obtained from SURVIAC.

JCAT Corner by Lt Col Dave Bartkowiak, USAFR, and Lt Col Jeff Ciesla, USAFR

The Joint Combat Assessment Team (JCAT) continues to provide first-rate support for the warfighter as the summer months shape up to be quite busy for our deployed personnel. LCDR Dave Schubkegel and Capt Jessica LoCasale have done an outstanding job during their time in Iraq, and will have their hands full as they make preparations to deactivate the OIF JCAT office. The JCAT office in Iraq will close by the end of summer, even as we deploy additional assessors to support coalition efforts in Afghanistan.

Shifting the focus to OEF, we now have four assessors deployed to various locations in Afghanistan and will have a fifth in place by the end of the fiscal year. Navy CDR Craig Fehrle was joined by LT Oral John and USAF Majors Rich Lopez and Mark Friesen. Everyone has "hit the ground running" to eagerly embrace their roles as JCAT inspectors.

A recent catastrophic incident in Afghanistan brought home the importance of what we do, and showcased the joint nature of our organization. CDR Fehrle and LT John responded to the scene immediately to begin the initial assessment, while USAF Majors Lopez and Friesen made their way to Camp Leatherneck to assist. As is typical with incidents of this magnitude, ASDAT (the Army component of JCAT) deployed its quick-reaction team to Afghanistan from Fort Rucker, AL, to assist with the assessment. CW5 Bobby Sebren, CW4 John Cappadoro, and CW4 Jim McDonough joined the rest of the

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An Introduction to Susceptibility Reduction

by Matt Crouch

According to Robert Ball, Susceptibility Reduction (SR)—also known as threat avoidance—is achieved by reducing the probability of an aircraft being detected, tracked, engaged, and hit. The Joint Aircraft Survivability Program (JASP) contributes to the susceptibility reduction of Department of Defense (DoD) aircraft through the efforts of the Susceptibility Reduction Technical Subgroup. The SR Subgroup, as it is known, is comprised of scientists and engineers from across the Services and DoD who are technical subject matter experts (SMEs) and leaders in their fields. Collectively, their mission is to advance existing SR capabilities and develop/assess technologies for advanced threats.

This team of SMEs assists in the coordination of SR efforts across DoD and functions as the selection panel for JASP SR investments. The Subgroup executes projects that offer clear, quantifiable benefits in reducing the probability of military aircraft being hit by enemy fire. The goal is to demonstrate or validate the component, technique, system/subsystem, model, or prototype in a relevant environment. Concepts range from ideas for improving the operational suitability of existing susceptibility reduction systems (*e.g.*, cost and weight reduction, increased reliability) to ideas for entirely new capabilities. The technical scope encompasses research efforts across the electromagnetic spectrum—infrared (IR), radio frequency (RF), visual, ultra-violet (UV), and acoustic. Ideally, the SR concepts and technologies developed by the Subgroup will be mature enough to transition to the warfighter.

Recently, the SR Subgroup has paid particular interest to a few topics, referred to as "focus areas." These are centered on the SR Subgroup's expertise and niche capabilities within the survivability community, such as complementing Service investments in Aircraft Survivability Equipment (ASE), the science and technology (S&T) of advanced threats, addressing shortfalls in testing, and the transition of enabling technologies into components. Current focus areas with examples of the relevant concepts or technologies include—

- Technologies or concepts that significantly benefit operational units in the near-term by solving an immediate need or capability gap. An example is developing or testing IR decoy flares that do not emit a visible signature.
- Technologies that improve Blue Force survivability through increased situational awareness (SA). Although the benefit of enhanced SA is difficult to quantify, technologies that improve SA have the potential to increase the effectiveness of existing ASE as well as improve or modify Tactics, Techniques, and Procedures (TTPs). An example is the development of compact acoustic sensors for Hostile Fire Indication (HFI) of unguided threats.
- Technologies or concepts that will defeat current and future generation multi-spectral threats such as MANPADS, imaging seekers, and search-and-track systems. Candidate technologies or concepts include low-cost approaches to multi-spectral missile countermeasures and warning devices.
- Technologies or concepts that will counter advanced coherent, parameter-agile radar threats employed against both manned and unmanned military aircraft, to include advanced and passive radars. Example concepts include advanced electronic attack and protection techniques.

The SR Subgroup's annual program takes a balanced approach, and is structured to address each link in the kill chain. Each project, whether its area of interest is countermeasures, signature reduction, electronic attack, mission planning/TTPs, or overall situational awareness, can be traced to an enabling technology to help break one of the detect-track-launch-guide-fuze-kill links.

The recent Study on Rotorcraft Survivability (SRS) confirmed that the SR Subgroup's technical scope and focus areas support the reduction of aircraft losses and fatalities due to hostile fire. The SRS identified investments to improve rotorcraft situational awareness, threat detection, and jamming as significant technology requirements to further reduce combat losses. The SR Subgroup recognizes the magnitude of these findings, and strives to advance technologies that keep the warfighter safe. ■

Competitive Prototyping for Infrared Countermeasures

by Barry Price and John Kamadulski

It is not hard these days to find a headline concerning a major defense program that has encountered significant cost overruns. The root cause of the cost overrun is often a shortfall in technology maturity that was not recognized before the program's start. The traditional acquisition approach limits flexibility when issues are encountered during development. Once a program enters Engineering Manufacturing and Development (EMD), the approach has often been to continue to work through any technical issues until they are resolved with the prime contractor. While cost and schedule overruns are painful, changing acquisition strategies in EMD can result in a program new start or the risk of program cancellation—thus delaying needed capabilities for the warfighter.

So how does the acquisition community lower the risks in development? Congress passed the Weapon Systems Acquisition Reform Act (WSARA) on 22 May 2009. WSARA includes a provision for competitive prototyping that provides an opportunity to gain an early understanding of program and technology risks and position the program properly in the acquisition process. Additionally, provisions for increased competition and modular open architectures offer options when issues are encountered during development. This paper will describe how competitive prototyping was used to help shape the Common Infrared Countermeasures (CIRCM) acquisition effort.

New Approach to Acquisition

The CIRCM program is being developed to provide Infrared Countermeasures (IRCM) protection for rotary-wing aircraft. The key tenets of the program are to provide a lightweight, highly reliable, and cost-effective solution for Army and Navy rotary-wing aircraft. Per the WSARA, OSD directed the Army to conduct a competitive prototyping effort prior to the initiation of CIRCM development. The goal of this effort was to demonstrate technical maturity, understand risk areas, and shape the CIRCM acquisition strategy.

Competitive Prototyping for CIRCM

Approach/Methodology

Between July and December of 2009, PM IRCM executed a competitive prototyping phase through the Intelligence and Information Warfare Directorate (I2WD) to evaluate the design maturity of five different IRCM designs. Interested vendors were solicited through a Broad Area Announcement (BAA). Criteria for contract award were that the vendor—

- Have prototype hardware available to support the immediate start of testing
- Have prototype system weight near the requirement

Five of the eight vendors who responded were awarded contracts worth approximately $2 million each. Winning vendors provided their own prototype hardware for the test, and were responsible for any repairs required during the testing process.

The statement of work for each BAA vendor was identical. Vendors were required to demonstrate their ability to integrate with a missile warning system, perform tests to evaluate energy on dome, execute a reliability characterization test, develop a conceptual A-kit design, and create a total ownership cost evaluation.

As illustrated in Figure 1, integration with the missile warning system was accomplished by using an Open Architecture Translation Systems (OATS) that accepted the data stream from the vendor's pointer/tracker and translated the data to a format that the warning system could recognize. The ability of the vendor's system to accept a target handoff and establish a laser-quality track within acceptable timelines was evaluated against the CIRCM performance specification.

Systems were evaluated in a realistic lab environment to determine their tracking accuracy against representative targets and target motion. Facilities for integration and energy on dome testing were provided by the I2WD at Fort Monmouth, NJ. Test articles were mounted on a table to represent platform motion while tracking simulated threat missile plumes on a moving target board. Lasers were also characterized to determine beam characteristics. Tracking accuracy and laser parameters were combined to determine the ability of the system to put energy on dome of an incoming threat missile, and were compared to values derived from system performance specifications to determine the probability of a successful countermeasure.

The temperature and vibration environment for reliability characterization testing was taken from the worst-case rotary-wing platform—the CH-47. Each vendor provided its own test facilities for this part of the test series. System components were subjected to the environment, with government witnesses available during all tests to record failures. Failure review boards were conducted with each failure event to document the root cause and approve the path forward to get the equipment back into test.

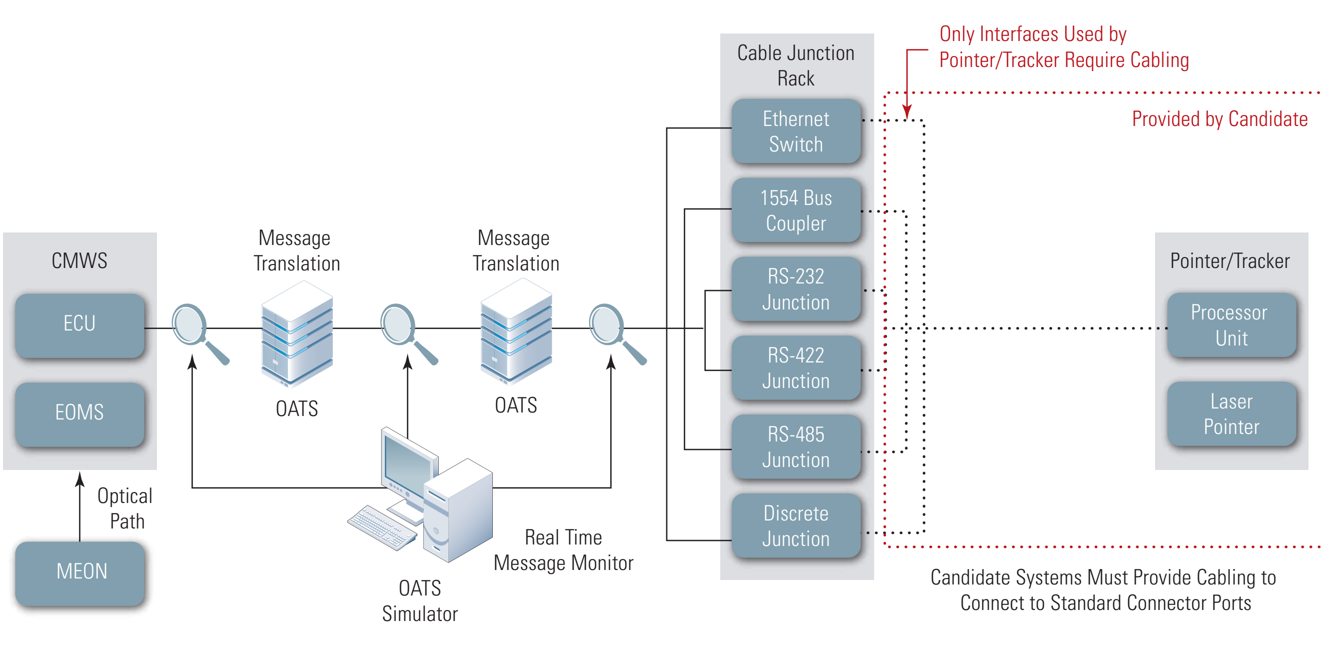

Figure 1 Pointer/Tracker Integration with CMWS

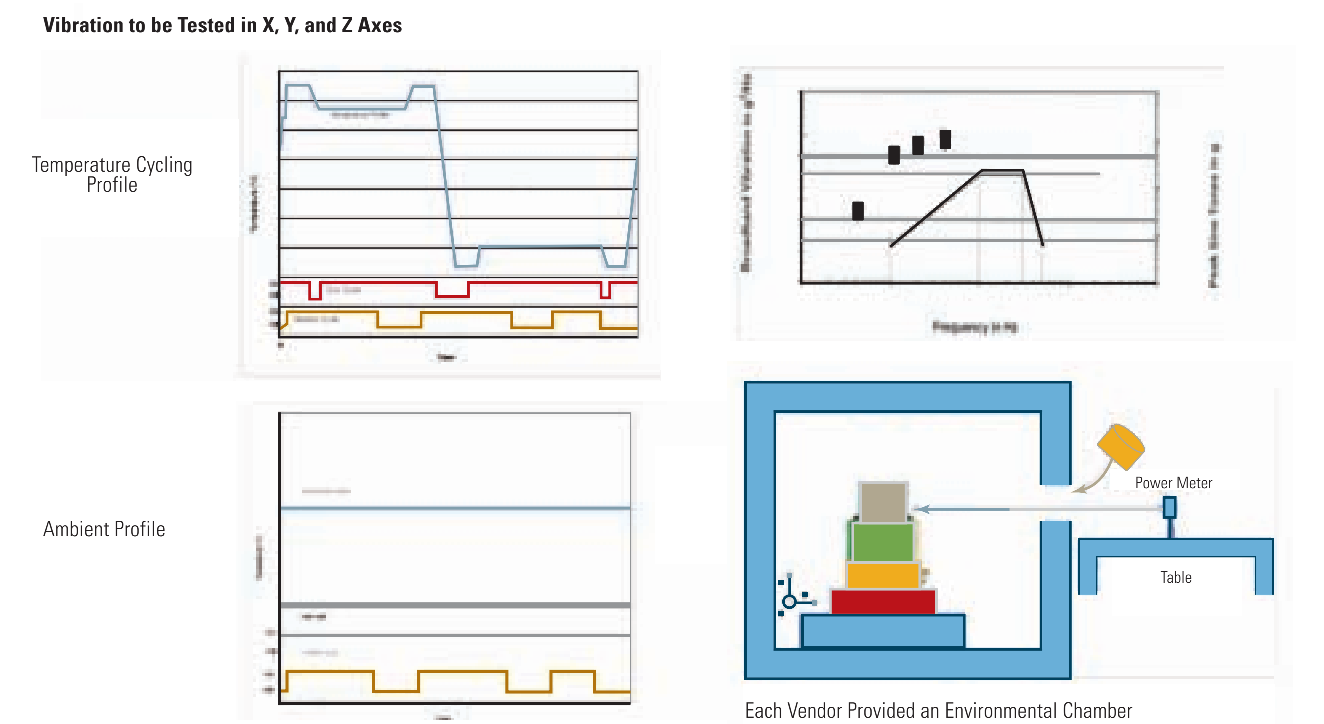

Figure 2 Defining the Temperature and Vibration Profile for Testing

A conceptual A-kit design was developed to allow each vendor to determine the optimum location for its system to obtain near-spherical coverage on a rotary-wing platform. Participants were given access to Army and Navy helicopters to gain an understanding of the design challenges associated with mounting hardware and cabling within the design constraints of the platform.

Conceptual designs included a high-level installation plan and a weight estimate for the A-kit.

Participants provided estimates for Operational Availability, Max Time to Repair, Mean Time Between Failure, and Failure Rate. These estimates were used by the government to perform a top-level total ownership cost evaluation on each of the systems.

Risk Assessment

A key step in the success of the CIRCM competitive prototyping process was the assembly of a multi-Service panel of independent infrared countermeasure subject matter experts (SMEs) to evaluate the risk associated with each of the design architectures. The SMEs—affectionately called Gray Beards—were selected from government and industry,

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Sustaining Survivability in Legacy Electronic Warfare Systems

by Lt Col Gene McFalls

Following my 10-year-old son's Little League baseball game, his coach told the players over and over that they need to slide when stealing a base. He then said, "I sound like a broken record." One of the players then asked, "What is a record?" As hard as it is to believe, most kids don't know what a cassette tape is—much less an 8-track or a record. What does this have to do with electronic warfare (EW)? I often use the music player analogy when explaining what it is like sustaining 20-, 30-, or even 40-year-old systems. The 542 Combat Sustainment Group (CBSG) at Robins Air Force Base, GA not only keeps the "records" viable, but maintains and sustains the "record players" as well. As you can imagine, finding turntables and needles for a 30-year-old record player would be problematic. It is no different trying to find backward wave oscillators, traveling wave tubes, and Zilog processors.

Covering the Bases

Defense Acquisition University courses encourage program managers to plan for sustainment "upfront and early." This becomes even more important when aircraft and systems stay operational for up to 50 years or more. The mission of the 542d is to deliver and sustain affordable, war-winning EW capabilities on time. That means keeping nearly 70 different EW systems with over 30 different software languages viable and effective in an ever-changing survivability environment. The 542d also supports 28 countries with 14 different systems and over $700 million in foreign military sales support. As the United States Air Force (USAF) lead for EW, the 542d is on board every mission—

- Towed Decoys
- Infrared Jammers
- Radio Frequency Jammers
- Missile Warning Systems
- Radar Warning Receivers
- Flare and Chaff Dispensers
- Electronic Support Measures
- EW Suite Controllers
- EW Test Sets
- Foreign Military Sales Support

Home Field Advantage

The incredible challenge of keeping all of this EW equipment functioning properly is augmented by the facilities available to the over 100 engineers working in the 542d. At their disposal is over 150,000 square feet of electronic/computer work area that is secure, TEMPEST, and features emergency power. There are two anechoic chambers, four screen rooms, and an Sensitive Compartmentalized Information (SCI) facility, as well as over 30 unique system laboratories and a similar number of threat generators. With continual upgrades and over $300 million invested, it is the largest integrated facility of its type.

Parts obsolescence and diminishing materiel sources are constant issues in sustaining legacy systems. Program managers and engineers from the 542d work closely with numerous contractors and vendors to rectify shortages. In some cases, engineers will redesign a part or line replaceable unit using new components or material to replace the unobtainable item. In other cases, the 402 Electronics Maintenance Group (EMXG) at Robins AFB will actually reverse-engineer the obsolete part to include remanufacturing and technical drawings, supplying the customer with an exact or improved form-fit-function part. This organization also performs redesigns of shop- and line-replaceable units using programmable logic devices to increase reliability and mitigate future obsolescence. In emergency situations, its engineering team utilizes a unique test philosophy that enables many legacy assets to be repaired even when no technical data is available—providing stopgap relief while other remedies are pursued. The organization has achieved MIL-PRF-38534 certification, one of only 40 companies worldwide—and the only Department of Defense facility—to do so.

Enterprise Focus to EW: The All-Star Team

In 2007, the USAF EW community decided to re-examine the business model for EW. Sustaining more than 70 different systems in the USAF alone is an extremely costly effort, and with the ultimate goal of consolidating and updating these systems the Electronic Warfare Life Cycle Management Group (LCMG) was created. In December 2007, the Chief of Staff and the Secretary of the Air Force signed the initial charter for the organization. The 542d played a key role—and in addition to creating the organization's framework, co-chairs the Technical Advisory Group and maintains the Secretariat for the LCMG.

The LCMG is based on a tiered structure. The top tier is the Senior Advisory Group (SAG), comprised of general officers/ Senior Executive Services (SES) from every major command as well as HQ/USAF, the Air National Guard, and the Air Force Reserve. The SAG establishes the EW focus and goals for the USAF, makes decisions, and advocates on behalf of EW during budget deliberations at the corporate level.

The second tier of the organization is the Technical Advisory Group (TAG), comprised of O-6/GS-15 EW stakeholders throughout the Air Force. Every major command has representation from both the operational and requirements divisions. Other agencies, such as Air Force ISR Agency (AFISRA), National Air & Space Intelligence Center (NASIC), and Missile & Space Intelligence Center (MSIC), are also represented. TAG meetings frequently have Army EW, Navy Crane, PMA-272, and Joint Electronic Warfare Center (JEWC) personnel in attendance.

The third tier is comprised of the teams of action officers established by the SAG. Based on recommendations from the TAG, the following Integrated Product Teams work throughout the year to tackle the major issues faced in EW—

- Investments and Requirements
- Hardware/Software Open Architecture Standards
- Countermeasure Techniques and Assessments
- EW Training and Culture
- EWISR and Operational Support Databases

Although the EW LCMG is a relatively new organization, it is beginning to gain momentum within the Air Force. During the last two Program Objective Memorandum (POM) cycles, the top five EW priorities in 2010 (and four of the top five in 2011A) were funded. The LCMG was also instrumental in developing the USAF EW Roadmap 2030 recently signed by Chief of Staff of the Air Force (CSAF) and Secretary of the Air Force (SECAF).

As a result of some of the early deliberations within the LCMG, the 542d established the Technology Insertion Office, whose mission is to leverage and incorporate advancements in state-of-the-art EW technology into the legacy systems sustained at Robins. This can be accomplished either with a slight modification to an existing component or with an Acquisition Category (ACAT)-level major program modification. A recent effort integrated digital components from the Joint Strike Fighter into the B-52's ALQ-155 system. There are several similar efforts underway to continue the migration and upgrade from the legacy analog systems to state-of-the-art digital systems.

Bottom of the Ninth

As the pace of technology skyrockets, the 542d is poised to take advantage. Our potential adversaries continue to utilize digital processing, advanced sensors, and wider portions of the electromagnetic spectrum. The USAF has made the commitment to move our aircraft survivability equipment from the analog to the digital realm. By leveraging the involvement in the EW LCMG with the experience of dedicated EW professionals, the 542d will continue to maintain and sustain legacy survivability systems and incorporate technological advancements to defeat threats and keep aviators out of harm's way. The 542d is taking the "record player" and upgrading it to an mp3. ■

DHS Counter-MANPADS Programs

by Kerry Wilson

Since 1980, Man-Portable Air Defense Systems (MANPADS) have been used to attack 35 civil aircraft worldwide, damaging 24 aircraft and claiming 500 lives [1]. Because aviation contributes more than $3.5 trillion to the global economy [2], a successful MANPADS attack against a US commercial passenger aircraft could have catastrophic economic impacts extending far beyond the tragic loss of life. The United States and other concerned countries have recognized the implications that the proliferation of MANPADS represents to global economic and political stability, and have taken steps to counter this threat.

Historical Perspective

In 2002, the White House Office of Science and Technology Policy identified MANPADS as a credible threat to commercial aviation. In response, a White House task force representing 20 agencies developed a multi-layered strategy to counter the threat, specifically focusing on three areas: (1) proliferation control and threat reduction, (2) tactical operations, and (3) technical countermeasures (Figure 1). In 2003, Congress directed the US Department of Homeland Security (DHS) to prepare and implement a plan to develop an "anti-missile system" for protecting commercial aircraft from MANPADS. The Counter-MANPADS Program Office was created within the DHS Science and Technology (S&T) Directorate to manage the technical countermeasures program. To address off-aircraft counter-MANPADS solutions and post-missile impact issues, DHS S&T also executed the Commercial Transport Survivability Study (CTSS), Project *CHLOE*, and Emerging Countermeasures Technology (ECMT) programs.

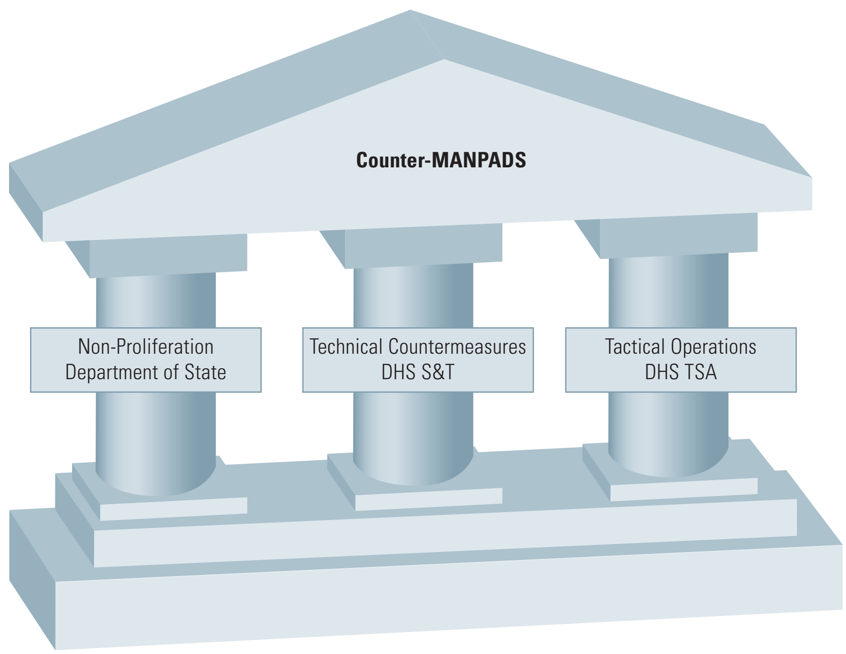

Figure 1 Counter-MANPADS National Strategy

Stakeholder Coordination

Interagency and stakeholder coordination were essential to the Counter-MANPADS Program. DHS S&T leveraged the expertise of government agencies and industry stakeholders to vet user requirements and concepts of operations, and ensure applicable regulatory requirements were addressed. Throughout the program, DHS S&T met with the commercial aviation community—including aircraft manufacturers, airlines, and pilot organizations—to present concepts of operations and maintenance, user requirements, and deployment issues, and to understand the industry's concerns and perspectives. Interagency and stakeholder working relationships are depicted in Figure 2.

Counter-MANPADS Program

The Counter-MANPADS Program mission was to develop, demonstrate, and evaluate technologies to protect commercial aircraft from MANPADS. During Fall 2003, the S&T Counter-MANPADS Program Office released a performance-based solicitation for countermeasures protecting commercial widebody and large-narrowbody aircraft. Of the original white papers received, DHS S&T invited five companies to submit full proposals and oral presentations. As a result of that source selection, BAE Systems (BAE), Northrop Grumman Corporation (NGC), and United Airlines (UAL) entered Other Transaction Authority agreements for Phase I. BAE proposed a variant of the US Army Advanced

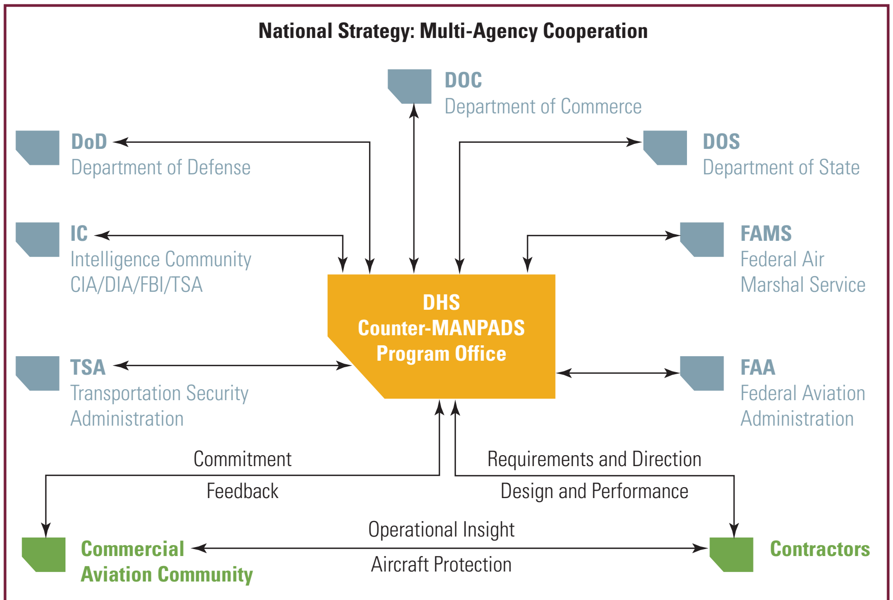

Figure 2 Counter-MANPADS Program Participants

Threat Infrared Countermeasures system and NGC a variant of the US Air Force Large Aircraft Infrared Countermeasures system. UAL proposed a flare-based solution with a prior application on large aircraft.

During the six-month Phase I, each vendor conducted trade studies regarding cost, maintenance, training, reliability, airframe, and avionics integration to generate preliminary system designs and performance assessments. At the end of Phase I, DHS S&T selected BAE and NGC Directed Infrared Countermeasure (DIRCM) systems to proceed into Phase II of the DHS S&T program.

Phase II began in August 2004 and continued through March 2006. During Phase II, BAE and NGC (hereafter referred to as “the vendors”) completed their detail designs, manufactured prototypes, integrated their solutions onto airframes, conducted ground and flight tests, and obtained Federal Aviation Administration airworthiness certification through Supplemental Type Certificates.

In 2005, Congress funded a third phase of the program to evaluate the suitability of the systems in a commercial aviation environment, and in 2007 funded an additional commercial passenger service evaluation. DHS S&T began Phase III in March 2006, and ended flight operations in June 2009. The vendors manufactured additional prototypes, installed and operated the systems on both cargo and passenger revenue flights, and accrued more than 16,000 hours of system data. Phase III also included a Live Fire Demonstration and additional test efforts to evaluate system improvements and technology protection concepts. Through these efforts, DHS S&T completed final performance and suitability assessments, further refined the DHS S&T Life Cycle Cost Model, and developed a set of deployment alternatives. To comply with the Congressional requirement to “develop a process for the delivery *and certification* of anti-missile devices,”

The DHS S&T Test & Evaluation and Standards Division partnered with DoD agencies such as the Joint Aircraft Survivability Program Office (JASPO) to prepare a certification standard for commercial DIRCM systems. The draft document standardizes the data and requirements necessary to assess the effectiveness and functionality of DIRCM system installations on commercial aircraft.

DIRCM System Performance Evaluations

DHS S&T structured a comprehensive, cost-effective test and evaluation effort with the vendors following the traditional triangular system engineering methodology shown in Figure 3. Each test phase is discussed in greater detail in the following sections.

Computer Modeling and Simulation

Computer-based modeling and simulation (ModSim) allowed comprehensive evaluation of many different scenarios. Both vendors completed extensive ModSim efforts in accordance with Counter-MANPADS program requirements and industry best practices. Assessment scenarios were selected based on typical takeoff and landing profiles at select US and international airports over a broad range of atmospheric conditions, aircraft types, and threat types, resulting in millions of engagement scenarios to predict system effectiveness. The results were substantiated by other test methods and formed the basis of the DHS finding

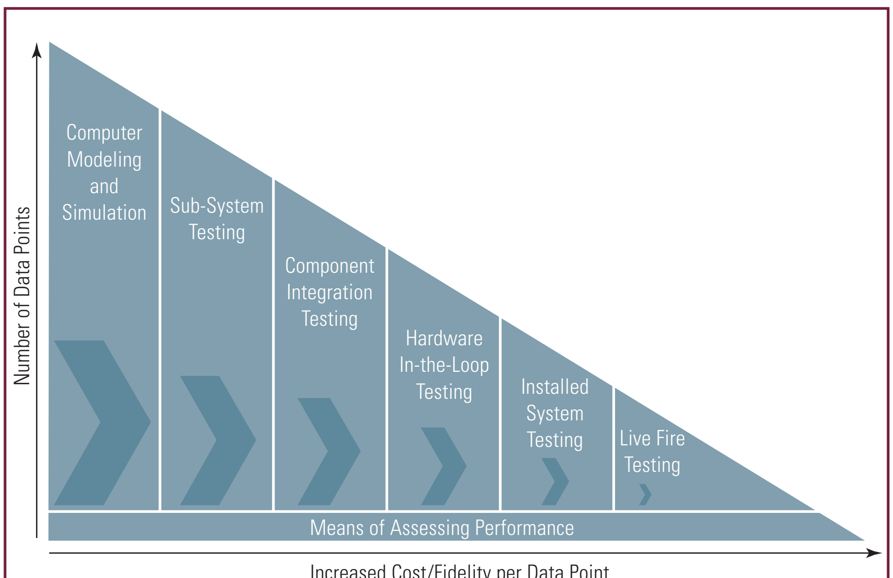

Figure 3 Counter-MANPADS Test & Evaluation Methodology

that both systems meet the program's simultaneous threat requirements with a single turret.

Subsystem and Integration Testing

Subsystem and integration testing included the conduct of component, subsystem, and system-level evaluations in a methodical building block approach at venues such as integration labs, test ranges, environmental chambers, and on the aircraft itself. Much of this data supported a comprehensive government functional configuration audit verifying compliance with thousands of design requirements.

Hardware-In-The-Loop (HITL) Testing

DHS S&T conducted hardware-in-the-loop (HITL) testing at the Guided Weapons Evaluation Facility (GWEF) at Eglin Air Force Base, FL to evaluate countermeasure effectiveness against real MANPADS seekers. These tests provided realistic testing in a controlled environment where many engagement scenarios could be repeated to achieve statistically significant results. The GWEF testing used real missile seekers and each company's laser in a high-fidelity HITL simulation of the engagement to assess the probability of miss given a successful detection and handoff. Missile warning, tracking, and associated timelines were predetermined from each vendor's ModSim results. The GWEF simulated the aircraft infrared signature, MANPADS launch, and flight maneuvers in real time throughout the engagement. High-fidelity Boeing 747 and 737 real-time Composite Hardbody and Missile Plume (CHAMP) infrared images simulating typical commercial airport departures were developed under this effort. These images compared favorably with radiometric air-to-air infrared measurements and existing Spectral and In-band Radiometric Imaging of Targets and Scenes (SPIRITS) models. DHS S&T worked closely with the GWEF to develop laser calibration and pre-test HITL validation methodologies. More than 5,000 missile engagements using various types of MANPADS were tested at various launch ranges and launch separation times around the targeted aircraft, demonstrating the relationship between probability of miss and time-to-impact in a multi-threat engagement with a single turret. The probabilities of miss for defeating these missile shots were averaged and compared to the system performance requirements and vendor ModSim results. The HITL results correlated well with the ModSim predictions, and overall met the system performance requirements.

Installed System Testing

DHS S&T conducted installed system testing at Eglin Air Force Base to evaluate each system's performance in the intended operating environment. The NGC Guardian™ system was installed on a MD-11 aircraft, accumulating 21 flight test hours, and the BAE JETEYE® system was installed on a 767-200 aircraft, accumulating 35 flight test hours. Three ground-based Mallina missile simulators provided the signatures of the MANPADS to trigger the installed counter-MANPADS systems. DHS S&T executed more than 1,200 valid threat simulations comprised of multiple simultaneous engagement scenarios for various ranges, azimuths, and flight profiles. DHS assessed JETEYE® and Guardian™ installed system performance timelines, pointing accuracy, laser energy levels, and factors such as aircraft structure blockages and aircraft vibration. Over the course of both the government and vendor flight test programs, BAE flew the JETEYE® system on two 767-200 aircraft and NGC flew the Guardian™ system on 747, MD-11, and MD-10 aircraft. Counter-MANPADS system improvements were made based on these flight tests and implemented prior to the operational evaluations in Phase III. Final system performance correlated well with vendor ModSim predictions.

Late in Phase III, DHS S&T conducted a performance demonstration with the BAE JETEYE® system at a high-clutter commercial airport during normal day-to-day operations (Figure 4). The 767 flew multiple low approaches while the DoD Joint Mobile Infrared Countermeasures Test System (JMITS), a high-fidelity missile simulator, triggered the installed counter-MANPADS system. In addition, DHS S&T collected JETEYE® infrared (IR) background data at multiple commercial airports to conduct ModSim assessments of performance in commercial clutter environments. This demonstration at Memphis International Airport and ModSim assessment confirmed that the JETEYE® system could detect a threat missile during normal commercial operations and meet system requirements.

Figure 4 JMITS Engaging Test Aircraft

Live-Fire Testing

DHS S&T conducted live-fire tests at White Sands Missile Range—Aerial Cable Range (ACR), NM to evaluate each system's ability to detect and counter real missiles. Twenty-nine MANPADS were fired at the counter-MANPADS systems attached to an elevated gondola emulating the rear-aspect infrared signature of a Boeing 747 departure (Figure 5). DHS S&T collected data on system logic and

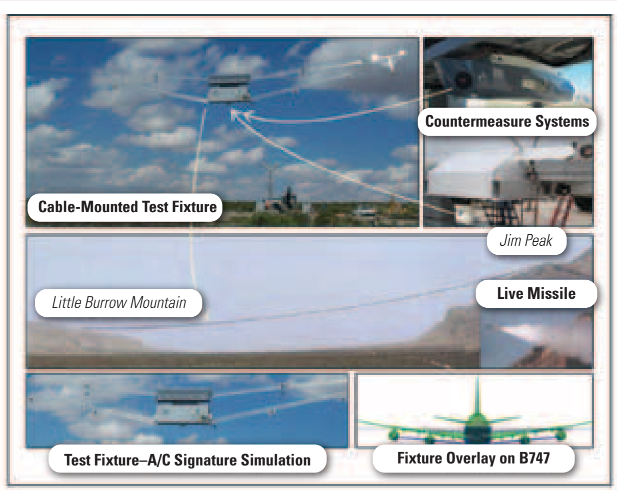

Figure 5 Live-Fire Test at White Sands Missile Range

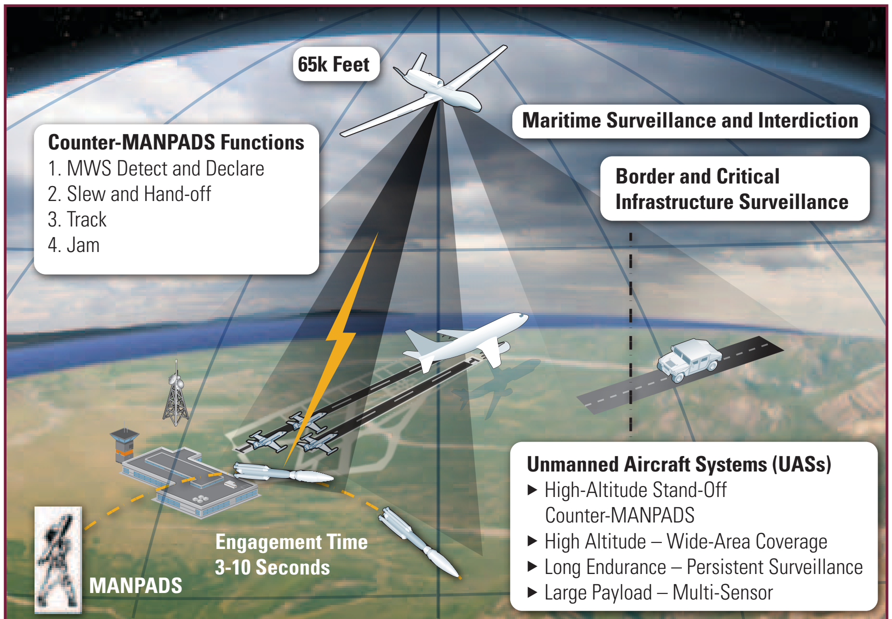

Figure 6 Project *CHLOE* Overview

Figure 7 *CHLOE* Sled Test

performance timelines to verify ModSim predictions, and conducted the first ever single-day triple event with multi-threat scenarios at ACR against a single-turret system. DHS S&T demonstrated that the systems can defeat multiple missiles under many attack scenarios, and the tests identified areas for improvement to expand effectiveness. Live-fire timeline and effectiveness performance were consistent with the flight test and HITL results.

Project *CHLOE*

The Project *CHLOE* (Figure 6) objective was to assess the feasibility of persistent high-altitude standoff counter-MANPADS protection of commercial aircraft and to evaluate attendant CONOPS and life cycle costs. A supporting objective was to investigate and demonstrate the feasibility of one or more Unmanned Aerial System (UAS) with Missile Warning Systems (MWS) and countermeasures stationed near airports to provide autonomous coverage for all aircraft within the MANPADS threat envelope. Secondary objectives were to investigate and demonstrate other DHS S&T missions and payloads compatible with the *CHLOE* platform and operating environment, and interface with air traffic control and law enforcement for situational awareness. These objectives were addressed *via* studies and analysis, ModSim, and three field demonstrations.

Leveraging the 2007 counter-MANPADS Phase III live-fire test at White Sands Missile Range, the Naval Research Laboratory modified a prototype two-color IR MWS, integrated it into a UAS surrogate (NASA ER-2), and passively monitored the MANPADS launches from high altitude (greater than 50,000 feet). This demonstration confirmed the concept of high altitude off-axis MANPADS detection and tracking, identified performance gaps, and helped refine *CHLOE* sensor/system requirements.

The second demonstration consisted of overflights of the Holloman High Speed Test Track by the Scaled Composites, Inc., White Knight aircraft (surrogate UAS) outfitted with a modified NGC Guardian™ pod in 2008 (Figure 7). MANPADS with radiometers were attached to a sled and fired down the track. The system flew above (greater than 45,000 feet) the track and detected, tracked, and lased the missiles. Data collected was used to refine the CONOPS, evaluate *CHLOE* MWS/counter-measure handoff timing and network requirements, and assess energy-on-dome levels. The demonstration was completed in September 2008.

The third demonstration consisted of laboratory testing of an NGC Viper™ laser against various MANPADS seekers to support *CHLOE* laser power requirements development. This experiment was conducted by Naval Surface Weapons Center (NSWC)/Crane during May–September 2009. Data will be used to quantify technology gaps and support requirements development.

DHS S&T has no current plans to conduct follow-on development of any of the system concepts evaluated in the *CHLOE* program.

Emerging Countermeasures Technology (ECMT) Program

In addition to the evaluation of the DIRCM systems, Congress directed DHS S&T to evaluate ECMT under a separate program. The ECMT Program Office evaluated three emerging civil aviation defense technologies utilizing other than onboard directed infrared countermeasures (DIRCM) to protect commercial aircraft from MANPADS. The concepts evaluated were the ground-based Raytheon Corporation Vigilant Eagle™, the ground-based

Northrop Grumman Space Technology's Skyguard™, and the onboard L-3 Communications AVISYS (L-3) Civil Aviation Protection System, Second Generation (CAPS2). All of the concepts evaluated in this program were considered immature from a commercial use perspective. DHS S&T has no plans to conduct a follow-on program to further investigate any of the system concepts evaluated in the ECMT Program.

Commercial Transport Survivability Study (CTSS)

The CTSS objective is to evaluate large aircraft vulnerability to MANPADS and identify potential mitigations by: (1) assessing likely MANPADS hit point locations and aircraft post-impact states; (2) assessing large high-bypass engine and control area vulnerability to MANPADS; (3) assessing large aircraft post-impact controllability; and (4) assessing and developing potential post-impact recovery tools and techniques. This study is being accomplished by a collaborative teaming arrangement with DHS S&T, TSA, JASPO, NASA, the USAF 46th Test Wing, Naval Air Warfare Center, and various aviation industry partners.

As a first step, DHS S&T and its partners conducted HITL simulations with missile seekers at the GWEF. The results include a set of MANPADS hit point locations, distributions, and aircraft post-impact states and controllability for Boeing 747 and 737 aircraft. This effort will also include a live-fire test on commercial aircraft engines. The USAF 780th Test Squadron (780TS/OL-AC) at Wright-Patterson Air Force Base, OH, will conduct a test with two operating General Electric (GE) CF6-50 aircraft engines at Naval Air Warfare Center, China Lake, CA, during fiscal years 2010 and 2011. Specially configured missiles will impact these engines, and instrumentation will collect appropriate impact, blast, and structural data for analysis to include modeling and simulations. The live-fire team will then conduct an assessment to determine the damage sustained by the engine and surrounding aircraft structure, followed by an assessment of controllability. Of particular note is that China Lake has developed a controlled missile launch method to accurately replicate the angle and velocity of impact based on wind tunnel testing and ModSim. Test results will provide better insight into the consequences of a MANPADS attack on commercial aircraft not equipped with countermeasures.

Also under the CTSS is the Propulsion Control Aircraft Recovery (PCAR) study, which leveraged Throttles-Only Control (TOC) and Propulsion Control Aircraft (PCA) survivability techniques and products developed by NASA in the late 1990s. These techniques and technologies were investigated by DHS S&T to recover attacked aircraft when normal flight control systems become totally or partially inoperative. This flight control augmentation technology will allow the pilot to safely land a damaged aircraft using the aircraft engine thrust and remaining aircraft control authority. For TOC, the pilot would manipulate the throttles to control and land the aircraft. PCA is a semi-automated version of TOC that allows the pilot to control the aircraft using the autopilot.

One objective of the PCAR study was to determine the degree of control available with manual manipulation of engine throttles for various transport aircraft. Simulations included Boeing 727, 737, 747, 757, 767, 777, MD-11, MD-90, C-17, and Airbus A320 and A300 transport aircraft. Preliminary missile impact effects were replicated using United Airlines flight simulators. The pilots used differential throttle control to generate sideslip, which, through the dihedral effect, resulted in roll. Symmetric throttle inputs were also used to control flight path. These tests demonstrated sufficient control capability for all tested aircraft to maintain gross control; both flight path and track angle were controlled to within a few degrees. These studies have also shown, for most aircraft tested, that using only manual TOC it is very difficult to make a safe runway landing due to difficulty in controlling the oscillatory phugoid and Dutch roll modes, weak control moments, and slow engine response. Engine location on the airframe was also an important parameter in determining TOC characteristics.

Another PCAR objective was to determine the recoverability of transport aircraft after total loss of hydraulics (TLOH), possibly the most common cause of total loss of flight controls. TLOH recoverability is defined as the ability to achieve straight and level flight within the aircraft flight envelope without grossly exceeding flap or normal acceleration limits. Recoverability tests were performed over a range of flight conditions and configurations for transport aircraft (including the C-17 military transport) and commercial transports, many of which have military derivative versions. Data supporting potential control software improvements and pilot recovery techniques were incorporated into subsequent flight simulator runs to determine the most effective means of enhancing aircraft survivability.

The CTSS will be completed in 2010.

Program Status

Based on vendor- and DHS S&T-directed tests and ModSim, DHS S&T determined that the DIRCM technology developed and demonstrated under this program can meet threshold requirements for defeating MANPADS. The prototype systems have demonstrated that the baseline technology can be deployed to the commercial aviation sector. However, there are issues such as export control, reliability growth, and technology protection that must be addressed to successfully execute an effective, sustainable, and affordable counter-MANPADS deployment on commercial aircraft. The Phase III report to Congress was submitted in March 2010; however, no decision to deploy has been made. ■

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Selecting a New Camouflage Paint for the CH-47F

by Fred Bacon, John Conant, and Frank Iannarilli, Jr.

In 2006, the US Army rolled out the first production model of the CH-47F Chinook helicopter, a new variant of the venerable transport helicopter. This provided PM-Cargo the opportunity to revisit the selection of a camouflage paint color. The Aircraft Green paint currently used by the Army was selected during the Cold War, when the principal battlefield was expected to be the forested terrain of central Europe. The dark green paint selected at that time was ideally suited for the temperate forests of Europe and the rain forests of Southeast Asia. However, in the first decade of the 21st century, the Army finds itself operating in a completely different environment. Could a more suitable color be selected? One that would reflect the current challenges and would perform no worse than the current choice under all conditions? The Army Aviation Applied Technology Directorate (AATD) and Aerodyne Research performed a collaborative study to determine whether a single paint color—and if so, which one—could yield reduced detectability across desert and vegetative terrain and against sky backgrounds.

The study sought an optimal single color tone from within a large subset of the Federal Standard 595 (FS595) color palette, which included various browns, greens, and grays. The best color tone was determined based on a non-spatial signature metric computed by the SPIRITS model (plus a small amount of post-processing) averaged over a matrix of backgrounds and viewing conditions. Conspicuity performance was gauged using the CIE dE94 color difference metric, a perceptual color metric developed to be uniform over the human visual color space.

Our analysis of the problem was guided by three principles—

1. Rigorous 3D signature prediction of object appearance
2. Evaluation of the contrast against background statistics (not just the mean)
3. Employment of an appropriate visual color difference metric

In the first case, the intent was to capture the complex interaction of 3D helicopter geometry, paint bi-directional reflectance distribution function (BRDF), non-isotropic panoramic illumination, and atmospheric effects, even if gauging average color across the whole target. Consequently, we employ the SPIRITS 3D signature model, which includes MODTRAN for atmospheric radiative transfer. Paint BRDFs and directional reflectance (DR) behaviors are based on CARC measurements; their spectral behaviors on measured spectral reflectance of FS595 paint samples.

The second guideline recognizes that stating contrast performance against a mean radiance value of a background is only partially informative. Real backgrounds, even within a single view, are spatially variable, and the scene produces not a single locus within a selected color space but rather a distribution of points. Since the helicopter's position against the background is essentially random, a more conclusive design evaluation must somehow gauge contrast against the statistical distribution of the backgrounds considered. Given two points equidistant from the mean background color, one may still be located with the distribution of background pixels while the other lies well outside of this distribution. It is our contention that the point that falls within the distribution will be less detectable.

To support this approach, AATD engaged in field collection of background imagery at two locations characteristic of desert and vegetative scenarios. In addition, Aerodyne conceived a methodology that allows computation of background trichromatic radiance distributions across a wider variety of scenarios. We validated this methodology against the collected background imagery.

The final guideline recognizes the need for a metric of human color perception to gauge the conspicuity of true-color (trichromatic) helicopter signatures against various backgrounds. At the ranges of interest (1km through 3km), the single color CH-47 is relatively featureless in appearance and subtends well below 1 degree of visual arc. Therefore, a visual spot detectability metric is reasonable.

A target or background color may be specified in any of the CIE color spaces (XYZ, Lab, xyY, *etc.*), but these spaces are not perceptually uniform. Color points equally spaced within, say, the CIE Lab space will not be seen by a human observer as having equal changes in their appearance. In particular, small changes in the luminance produce a larger change in appearance than an equivalent change in the chromaticity. Furthermore, the effect varies as a function of the location within the color space. For our analysis, we needed to be able to quantitatively compare two or more colors to a reference (background) color and predict which one a human observer would consider the closest match in the event that there was no exact match. For this study, we chose the CIE dE94 color difference metric, which handles the combined effects of luminance and chromaticity along with their non-linearities. We argue that reducing the dE94 contrast metric reduces mean trichromatic contrast, and will thus reduce detectability as well.

Helicopter Signature Modeling

The entries in the paint FS595 palette were measured and fitted to an angularly and spectrally dependent reflectance model. The angular behaviors were based upon BRDF and DR measurements of Army CARC paints, with BRDF data taken at 540nm wavelength and DR data taken spectrally from the ultraviolet through the infrared. Spectral dependence is based on the spectral DR measurements in the case of CARC paints, or on normal-incident spectral reflectance measurements of actual FS595 paint samples. These were collected using a commercial "Eye-One Photo SG" spectro-photometer (Gretag Macbeth GRET-0366), which provides 10nm resolution across the 380-730nm spectral range. The paints were assigned to a 3D geometry of over 20,000 facets. Renderings were made hyperspectrally for 54 spectral points and ~1cm image pixels, using reflections from the sun, earth, and (multiply scattered) sky.

Background Images and Colors

This effort considered three categories of terrain backgrounds—desert, vegetative, and clear sky. We score each target projected-area-average color against a set of sampled background colors for each category, setting aside higher-order spatial contrast measures such as texture contrast. Our process therefore does not require background images, but merely sampled background colors.

We utilized modeled backgrounds because that enables us to broaden the "background gamut," *i.e.,* the range of scenario conditions under consideration, beyond that of the collected imagery. It also ensures that the scenario descriptions were identical for background and target. However, measured background images were still required to—

1. Validate the background color statistics we imputed, and
2. Embed computed target images into background images as sample scenes used to jury-calibrate the dE94 metric. True-color background imagery was acquired at Yuma Proving Ground (YPG), AZ and Winterhaven, CA for desert; and at Carmel Valley and Monterey, CA for vegetative.

We simulated the random distribution of background radiances using SPIRITS, varying surface orientation relative to sun, sky, and observer. This concept includes surfaces oriented away from the sun (shaded), but neglects variations in surface type, inter-reflections, and shadowing between neighboring elements.

For each background type and environmental condition, we generated a cluster of several hundred color points (in 3D tristimulus radiance space), then analytically selected 13 points from each cluster along its principal axes. We selected color points at the mean and at ± one and two standard deviations along each of the three axes. This statistical approach was validated against the measured background images.

Color Differences

To compute a dE94 perceptual difference value between a given computed CH-47 trichromatic mean radiance and background, we apply the standard CIE equations—normalizing both the target and background CIE XYZ values to a common white point XYZ value. The dE94 metric applies to an observer whose attention is already focused to the task of discriminating a uniform two-degree subtense "target" spot viewed against a uniform extended reference background. Nevertheless, vision research indicates that the dE94 metric is monotonic to target discriminability for search in clutter. If anything, it will tend to overestimate the detectability of the target.

To "calibrate" this numerical metric to an absolute scale meaningful within the Army context (search in clutter), we conducted an informal visual jury test. This involved having project members view a series of helicopter-in-background imagery, chosen to be at various dE94 values ranging from undetectable through readily detectible. The result was a treatment payoff scale, where helicopter-to-background contrast dE94 values were classified into three categories—good, marginal, and poor payoff.

In the first stage of our effort we considered 72 FS595 paints, each applied as a monocoat onto the CH-47. The helicopter area-average tristimulus radiances were computed for 10 combinations of sun and viewing angles. Color dE94 distances were computed between each CH-47 radiance triplet and the 13 sampled terrain background triplets for each of the two types of desert and vegetation at 1km range, and also against MODTRAN-computed sky backgrounds at four different view azimuths. By finding minimum dE94 values, we were able to identity best-match CH-47 paints against each background type and against multiple backgrounds together. We then down-selected from 72 paints to the optimal overall and scenario-optimum FS595 choices shown in Figure 1. The "Best Overall" selection equally weights performance against desert/vegetative/sky backgrounds (33/33/33%). The best-overall paint is negligibly affected by inclusion/exclusion of the sky backgrounds.

In our second-stage effort, we conducted an extensive payoff evaluation of the schemes selected in the first stage (Table 1). The corresponding computed helicopter signatures were evaluated against the two desert and two vegetative reflectance-sphere terrain backgrounds, plus MODTRAN-computed sky backgrounds, at 1km and 3km range across a matrix of (2 observer ranges) x (8 observer azimuths) x (4 solar positions). All computations include the proper relative-azimuth-dependent sky foreground effect (*i.e.,* viewer azimuth relative to solar azimuth).

Conclusions

Although individual case results are not shown here, we note that the relative ranking of paint-tones is maintained across "cases" (range + relative solar azimuth + time of day/solar elevation) within a given background category. As one might anticipate, we obtained much more optimistic performance results at the 3km range versus 1km. Not only does the target subtend a smaller visual angle, its color difference is reduced due to increasing foreground atmospheric path radiance. In fact, different (more optimistic) conclusions ensue if one only considers performance at 3km.

Table 1 Optimal Paint-Tone Choices, Plus Baseline

FS Name	Purpose	Sample
30372	Best Desert	
34095	Best Vegetation	
36307	Best Sky	
34201	Best Overall	
30372/34095	2-Color Camo	
34031	Baseline	

The performance against desert terrain is more variable than against vegetative terrain, as reflected in higher average dE94 values. The sky is the *most difficult* background to match, as there is substantial variation with azimuth to the sun. Moreover, this variation occurs between "poles" of maximal contrast opposition conditions—(a) back-lit, where the dark-shaded side of the helicopter is viewed against the bright, forward-scattered sky; and (b) front-lit, where the sunlit helicopter is viewed against the darker, back-scattered sky.

Our results led us to make the following recommendations and conclusions—

- ➤ If support costs can be borne, deploy monocoat optimized "green" (FS34095) in vegetated regions and optimized "tan" (FS30372) in desert regions
- ➤ No effective solution exists against the near-horizon sky due to the large variance in sky brightness with sun position
- ➤ A marginal monocoat solution exists (FS34201) for joint vegetated/desert terrains, which provides moderate benefit over Aircraft Green

Figure 1 is a photograph of the helicopter with the best-overall paint FS34201 applied as part of an evaluation test. [1] ■

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Figure 1 Photograph of CH-47F with FS34201 (Woodland Desert Sage) Paint Applied.

Going Beyond ASE: Aircraft Survivability and EW/DCGS—Enterprise

by Isidore Venetos and Scott Hayward

The rotary craft platforms of today's Army are taking on an even more critical role in the Afghanistan operations, where road infrastructure, harsh terrain, and large areas of operation mandate combatant commander reliance on combat aviation brigades (CAB) for many warfighter ground infrastructure requirements. Army aviation is used, with five different aviation brigade structures, in the active force—general support aviation battalions, assault battalions, light attack/reconnaissance squadrons, heavy attack/reconnaissance battalions, and aviation service and support battalions. Each of these structures brings forward many different types of aircraft platforms, all having unique requirements and capabilities for aircraft survivability.

The criticality of aviation in the current theater of operations makes this a high priority target in an environment whose mountainous regions pose a huge obstacle to meeting mission requirements. Valleys become corridors, forward operational bases become convergence points, terrain elevation becomes aircraft ceiling limitations, line of site becomes a communication limitation, and rough terrain with many nooks and crannies becomes a situational awareness nightmare. Aircraft tactics, techniques, and procedures (TTPs) are impacted by the environmental conditions found in Afghanistan, resulting in the enemy being able to observe and determine specific patterns. This enables the enemy to make predictions on where our air platforms will be, determine our tactics, and even use small arms fire and rocket-propelled grenades (RPGs) to damage our aircraft.

Predictability Increases Vulnerability

The predictability of rotary craft platforms leads to an increase in vulnerability that is especially prevalent in the Afghan theater. This translates into a shorter timeline against traditional advanced threats such as man-portable air-defense systems (MANPADS), and to less sophisticated threats like small arms fire and rocket-propelled grenades. Hence, we face a need for Aircraft Survivability Equipment (ASE) that can detect a variety of threats, identify threat type, and respond with appropriate countermeasures (CM) within a very short timeframe. The requirements for meeting these shorter timelines stress the current ASE suites to their limits.

The best way to counter these threats is with an improved methodology for developing situational awareness that expands beyond a single airborne platform to one that includes sensors in addition to the ASE sensors. Countermeasure responses could also be improved with this improved situational awareness, which would focus on real-time tactical operations. New TTPs or more sophisticated CMs could be developed that are optimized in accordance with a better understanding of real-time tactical operations. The resulting improvement would provide more effective kinetic responses, lasers, chaff, and flares against the variety of threats. The CM

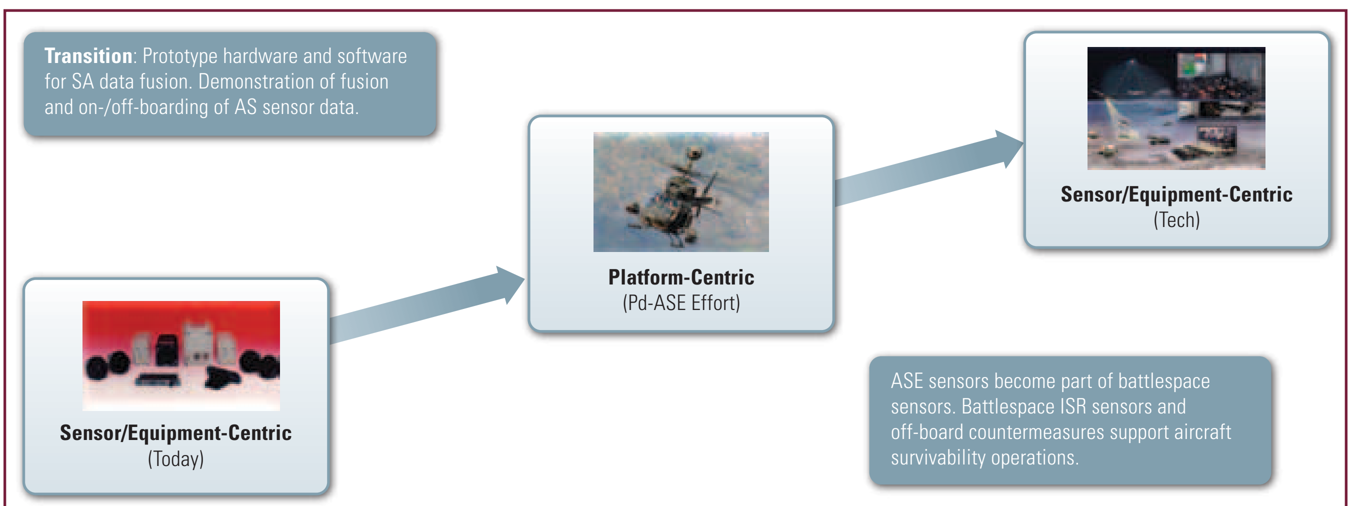


Figure 1 The Army's S&T Progression to the AS-Enterprise Vision

Table 1 Progression From a Sensor/Equipment-Centric Perspective to An Enterprise-Centric Effort

	Equipment-Centric (Today's Systems)	Platform-Centric (PM Effort)	Enterprise Centric (S&T Effort)
EW Spectrum Exploration	One spectrum-oriented	Multi-spectrum correlation	Multitude of battlefield sensors and intelligence data
Field of View	Restricted to one platform sensor aperture	Multiple spectrums on one platform	Sensor networks of a multitude of apertures on many platforms
Processing/ Analysis	Subject to one sensor's processing—onboard platform	Cross-sensor processing—onboard platform	Situational awareness/full data fusion—on- and off- board, including analysts
Situational Awareness	Alert/warning-based approach	Multi-warning based approach	Battlespace awareness and collection
Correlation	Focused on platform sensor only	Focused on platform	Improved survivability and situational awareness (utilized dropped data from current ASE sensors)
Countermeasures	CM limited to platform	CM limited to platform	CM includes platform & EW battlespace management
Data Exchange	Internal to sensor	Platform bus architecture to multiple sensors	Platform bus architecture and off-board data links

responses on board could be optimized by responding to the actual EW signatures being received by the multiple sources. CM attacks could also be coordinated with multi-platform attacks, and with platforms not dedicated solely to aircraft protection.

Benefits of an Enterprise-Centric Approach

The short timelines, prevalence, and portable nature of the aircraft threats described lead us to a change in the paradigm of aircraft survivability. Figure 1 illustrates the progression towards a new vision of improving situational awareness for aircraft protection and the benefits of moving toward an enterprise-centric vision for aircraft force protection. The Army's research and development labs are exploring this paradigm with a new non-Army Technology Objective (ATO) called Battlefield Integrated Aircraft Survivability (BIAS), managed by the Intelligence Information Warfare Directorate (I2WD) at Fort Monmouth, NJ. Its vision is that existing ASE sensors will become one of many types of sensors—including ISR sensors—on the battlefield. This will exponentially improve overall battlespace situational awareness, and in turn improve aircraft survivability. The first column in Table 1 lists the fundamental functional components of ASE. The table as a whole highlights the improvement of moving from an equipment-centric perspective to one that is enterprise-centric.

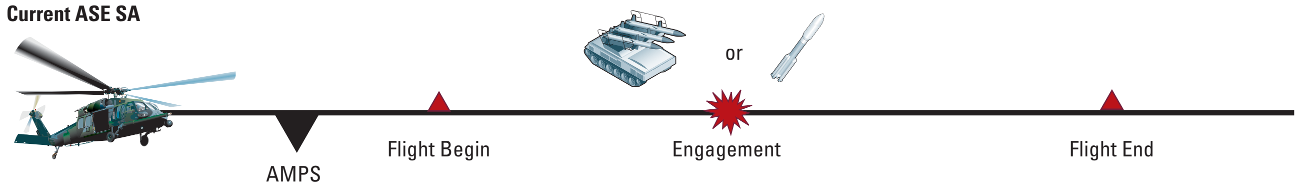
Improvement in Responding to Short Timelines

The implementation of AS Electronic Warfare (EW)/Distributed Common Ground Surveillance (DCGS) enterprise architecture improves situational awareness by overcoming some of the issues of the short timelines associated with the prevalent threats found in OEF. Detection of threats by a multitude of ASE and/or ISR sensors is improved not only by the increase in the number of sensors, but also by the fact that different parts of the EW spectrum are exploited and correlated. In addition, sensors that are not solely dedicated to an ASE mission are utilized for force protection—including functional elements for the predication of hostile events. The probability of detection prior to an engagement depends on the type of threat, but if ISR sensors are detecting threats before the mission with RF, IR, and visible sensors, this information can improve responses to short-timeline threats.

Networking ASE & EW/DCGS Platforms Into the Battlespace

The AS & EW/DCGS – Enterprise architecture allows the operational commander and the aviators to engage or avoid threats in ways that are not possible today. The first key element of the AS & EW/DCGS – Enterprise architecture is establishing an operational network amongst airborne and ground elements to exchange messages, and the second is dynamic mission planning where other airborne and ground platforms are capable of responding in the real-time operational environment. An obvious example of this networked aircraft survivability approach is that if an aircraft is engaged in hostile fire and another aircraft is approaching the same area, the second aircraft will already have the appropriate situational awareness to handle the threat even before it enters the engagement area. Another advantage is that threat avoidance becomes part of the real-time environment. If a threat has been spotted by other platforms, spot reports can be generated to alert others not to

Current ASE SA



SA Sources \ Events Timeline Rqmts	Pre-Mission Analysis	Not Real Time	Real Time	Not Real Time	Post-Mission Analysis
ASE-On Board		+	+		
ASE-Off Board (other platform)					
SPOT Reports BFT					
DCGS-A					
ISR-Sensors					
AS/INTEL Enterprise		+	+		

Key: Near Term Capability + Far Term Capability +

Figure 2 Aircraft Hostile Engagement Against Situational Awareness Sources (Today)

fly in a particular area or flight plan. Such dynamic mission-planning aspects would provide a new level of force protection that does not exit today.

AS-Enterprise is evaluating the possibility of leveraging the existing Blue Force Tracker (BFT) program's networking capabilities for synchronization, maneuver, and fire through shared situational awareness. BFT—which provides leaders the capability to navigate confidently in unknown terrain and during reduced visibility—could prove to be invaluable in the aircraft survivability paradigm when applied to this AS-EW/DCGS architecture. Another primary value attained by leveraging BFT structures into the AS & EW/DCGS – Enterprise usage would be the automatic Blue and Red Hazard SAs, which could be disseminated both vertically and horizontally throughout the battlespace. The BFT structure could also provide real-time spot reports to aviators in support of the dynamic environment that they are encountering. This real-time access to disparate platforms makes the BFT dissemination structure, along with the Tactical Airspace Integration System (TAIS), a very valuable part of the AS-EW/DCGS architecture.

Working With the Intelligence Community

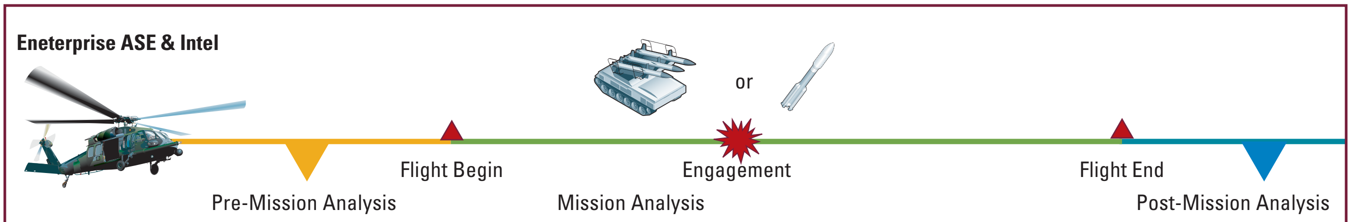
The Intelligence Community has been focused on providing actionable intelligence to the commander by establishing a common operating picture (COP) for air and ground operations. Army intelligence is typically analyzed and distributed by the DCGS system. Intelligence, surveillance, and reconnaissance (ISR) sensors throughout the battlespace may also be tasked and controlled from DCGS to enable persistent surveillance capabilities. The Intelligence Community indirectly supports the force protection mission of airborne platforms with spot reports and debriefing summaries. The BIAS program will specifically look at how existing intelligence capabilities can potentially reorder information flow and ISR tasking to support the protection of airborne systems. The most significant issue is providing real-time data from DCGS.

Today's reality is that the DCGS system will not support real-time data requirements for force protection of aviation platforms. However, pre- and post-mission planning can be significantly improved to support airborne operations with a real-time solution now in development that focuses on the force protection of airborne assets. The Intelligence Community can transform the meaning of pre-mission planning—where today ASE loads for aviators are programmed into load sets containing mission data to represent the most likely threats to be encountered, tomorrow we will be able to provide dynamic updates based on the operational status of the area of interest (AOI).

Figure 2 and Figure 3 represent the transition to an improved situational awareness. Threats could be avoided through a recommended flight route, or threats engaged with the appropriate response using air and ground assets if required. The intelligence data could be as simple as providing information on a low-priority threat indicating a spotter with communications on a mountaintop, to a more complicated scenario where an EW asset is assigned to prevent the spotter from communicating with a group that intended to fire on incoming airborne platforms. The DCGS is also evolving to a cloud computing architecture able to support real-time dynamic operations with servicing data.

Acquisition Challenges

The final solution for aircraft survivability should not depend on the networked solution—it should be enhanced by the networked solution. The AS-Enterprise solution offers many advantages, as outlined in Table 1. The tradeoff is complexity and reliance on the network. The final solution will need to ensure that the equipment and platform sensor and countermeasure solutions are still highly reliable, not degraded in performance, and able to function on their own without the enterprise. The AS & EW/DCGS – Enterprise networked



SA Sources / Events Timeline Rqmts	Pre-Mission Analysis	Not Real Time	Real Time	Not Real Time	Post-Mission Analysis
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ASE-Off Board (other platform)	+	+		+	+
SPOT Reports BFT		+	+	+	
DCGS-A	+	+	+	+	+
ISR-Sensors	+	+		+	+
AS/INTEL Enterprise	+++	+++++	++	++++	+++

Key: Near Term Capability + Far Term Capability +

Figure 3 Aircraft Hostile Engagement Against Situational Awareness Sources (Future)

solution will enhance survivability, and in some cases drive additional functional requirements onto the sensor and platform systems. Hence, the challenges will be looking at aircraft survivability not only as a sensor- or platform-centric solution, but also as a battlespace EW and ISR solution set. Bringing together the legacy ASE with the appropriate data links and multi-platform sensors/countermeasures, and adding in new functionality, will be a huge challenge for the Army acquisition community. One positive is that the development costs of bringing ASE, EW, and ISR fields into the AS-Enterprise can be shared among these fields, benefitting the overall acquisition strategy by not over-burdening a single source of funds.

Army labs will need to work with at least three Army Program Executive Offices (PEOs)—including PEO IEW&S, PEO Aviation, and PEO C3T—to implement an initial solution. Successfully working with these multiple domains will require an agreed-upon AS & EW/DCGS - Enterprise architecture, and relating lab programs to each of the specific acquisition program managers. The Army's Research, Development, and Engineering Command (RDECOM) has started this process by establishing the Technology Focus Teams (TFTs)/System Integration Domains (SIDs). The process is meant to ensure transition of technologies across RDECOM to programs of record (POR). An aircraft survivability technology roadmap has been established under this process to put together a unified vision of where Army labs should invest their limited research and development funding. The Air System Integration Domain (Air-SID) has begun a process of investment strategy that could eventually establish a common Enterprise Architecture for the AS & EW/DCGS - Enterprise.

Conclusion

The transformational capability of the AS – Enterprise will combine pre-mission analysis, real-time decision processing, and post-mission processing to provide integrated operational and intelligence situational awareness for airborne platform protection. The result will be a solid knowledge base of threats our adversaries plan to use; an early warning knowledge base of what an airborne platform might encounter; and a planned countermeasure response once threats have been encountered. Countermeasures may be synchronized with other battlespace assets to provide an optimized detection, classification, location, and countermeasure response. The problem of threats with associated short timelines will be alleviated with improved situational improvement—not only for the pilot, but also for the entire battlespace. ■

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Excellence in Survivability—Frank Barone

by Robert Lyons

The Joint Aircraft Survivability Program Office (JASPO) takes great pleasure in recognizing Dr. Frank Barone for his continued support of the Joint Aircraft Survivability Program (JASP) and his exemplary leadership in the development and testing of aircraft countermeasures. Truly a national treasure, Frank is an internationally recognized expert that "tells it like it is and gets the job done." JASP is very fortunate to have had Frank's involvement since the early 1990s.

The Joint Aircraft Survivability Program Office (JASPO) takes great pleasure in recognizing Dr. Frank Barone for his continued support of the Joint Aircraft Survivability Program (JASP) and his exemplary leadership in the development and testing of aircraft countermeasures. Truly a national treasure, Frank is an internationally recognized expert who "tells it like it is and gets the job done." JASP is very fortunate to have had Frank's involvement since the early 1990s.

Frank grew up in the Williamsburg neighborhood of Brooklyn, New York, where he watched and eventually helped his father—a licensed electrician who would later work as a teacher—wire large factories and homes. Frank's interest in anything electrical/electronic grew, and he obtained a PhD in Electrical Engineering from the Graduate Center of the City University of New York, then part of the State University of New York (SUNY) system. While earning his PhD, Frank once again followed in his father's footsteps and taught at The City College of New York.

In 1980 Frank moved south to the Washington, D.C., metro area, where he joined the Naval Research Laboratory (NRL). He has been actively involved with optical sciences ever since, and his area of expertise is the development and testing of Infrared Countermeasure (IRCM) techniques. Frank's specialty is the development of laser-based jammer techniques, and he has conducted groundbreaking research into the effects of optical scatter on the countermeasure susceptibility of infrared (IR) seekers. His research has directly led to the understanding of—and ability to explain—this phenomenon, significantly increasing the state of the art for laser countermeasures. Frank is currently expanding the state of the art with his work on imaging seeker IRCMs.

An F/A-18C "Hornet" from the "Shrikes" of Strike Fighter Squadron Ninety-Four (VFA-94) fires off flares during a training mission. US Navy Photo by LT Steve Lightstone.

During the 1980s Frank helped in the development of jam codes for Navy and Marine Corps operational jammers, for which he received the Technology Transition Award. He assisted in the development of directional jammer technology under the Navy Electronic Warfare Advance Technology (EWAT) and Navy Future Capabilities (FNC) programs, and also led the Navy's effort to develop flare requirements to defeat advanced seekers. In addition, he was the developer of the Department of Defense (DoD) standard for IR emulative missile modeling—the Digital Infrared Seeker and Missile Simulation (DISAMS). Recently, Frank served as Chief Scientist for the Department of Homeland Security (DHS) Counter-MANPADS program, where his efforts successfully supported a congressionally mandated demonstration of IRCM technologies on US commercial airlines.

Frank currently leads the NRL's laser jammer laboratory, where he took over following Bill Goodell's 1987 death in an automobile accident. Bill was Frank's mentor at NRL, and was a great guy. The Military Sensing Symposium (MSS) IRCM Specialty Group later renamed its IRCM Distinguished Service Award as the "Bill Goodell Memorial Award," which Frank was honored to receive in 1995 for his contributions to IRCM development. The MSS further recognized Frank in 2001 by naming him an MSS Fellow for his sustained significant contributions. Frank is now doing the mentoring, and is proud to watch as the engineers and scientists in his lab “come into their own” with respect to DoD credibility and technical expertise.

Along the way, Frank has found the time to publish over 50 papers of classified literature; serve as chairman of the Infrared Information Symposium (IRIS) IRCM Committee; sit on the National Defense Industrial Association, Combat Survivability Division Executive Board; teach at Northern Virginia Community College; and support the JASP by chairing its Susceptibility Reduction Subgroup.

Frank’s accomplishments are impressive. However, it is not until you talk to the people who know and work with him that you really get an idea of his knowledge, common sense, and integrity. Universally, those who have worked for or with him, or who he has worked for, all had similar things to say during my interviews—that he is “expert, solid as a rock, truthful”; “does what he says he will—which is rare”; “brings PhD-level smarts and common sense together”; is “one of the few people that really understands the problem”; is “technically honest”; “gets the job done”; “knows what he is talking about”; and my personal favorite, “he’s Mr. IRCM for the Navy.” I could go on since there was no shortage of the positive comments I received—but you get the idea.

Frank understands life’s priorities, and brings this same dedication and industriousness to his life outside of work. His wife is a master gardener who fills their house inside and out with flowers. Frank takes great interest in the activities of his three children, which has included coaching his son’s soccer league and, more recently, being involved with his daughter’s riding in English horse-jumping shows. And until the NRL softball league died out, he loved to play. So if anyone is interested in starting up the league, I think I know a second baseman...

It is with great pleasure that JASPO honors Dr. Frank Barone for his Excellence in Survivability contributions to JASPO, the survivability discipline, and the warfighter. Well done! ■

JCAT Corner

Continued from page 6

team directly from the airplane and quickly got to work. As the team was overcoming the many challenges related to the site’s austere nature and completing its assessment, parts from the aircraft were sent back to the Structural Materials Evaluation section of the Air Force Research Laboratory at Wright-Patterson Air Force Base for further engineering examination. This was a true team effort that will surely help with future survivability enhancements.

In April, the USAF component of JCAT hosted the annual Threat Weapon and Effects Training Seminar at Fort Walton Beach, FL. Each year the team attempts to inject new and noteworthy topics to keep the seminar fresh and interesting. This year there were some new topics on Unmanned Air Vehicle (UAV) survivability. A series of briefings on UAVs provided key insights into this new and evolving field of importance. As the dynamics of operations change, this area of interest is sure to receive more attention.

As is the case every year, the live fire demonstrations at the range proved to be the highlight of the event. This year’s target was a UH-1 helicopter. However, in a new wrinkle this year the helicopter was instrumented prior to being shot with small arms and an RPG. The instrumentation was added in an attempt to gather data critical to better understanding threat dynamics and their effects on crew members. All of the live fire shots at the range went off successfully.

Hot on the heels of the successful 2010 Threat Weapon and Effects Training Seminar was the scheduling of next year’s seminar for 26–28 April 2011 at Hurlburt Field, FL. The Navy component of JCAT will lead the coordination effort. Recent events in Korea have spotlighted several challenges that we have not really faced for quite some time…namely, nation-state players with advanced weapons such as air-to-air and surface-to-air missiles. The 2011 Seminar will focus on some of these larger systems and their implications in future scenarios. Save the date, and we’ll see you in Florida.

It was a great promotion cycle again for deploying JCAT personnel. Congratulations are in order for newly promoted Capt LoCasale, as she was recently named the Company Grade Officer of the Month for the 732nd ELRS. Majors Lopez and Friesen were recently promoted to O-4; and among the US Navy reservists, Kevin Askin, Craig Fehrle, and Cliff Burnette were selected for Captain. Additionally, Dave Storr recently pinned on an O-5. As seen by recent promotions across all of the Services, our mission is viewed as a key force multiplier by the warfighters, regardless of their Service branch. These promotions prove that the JCAT mission continues to be viewed as essential in our ability to conduct combat operations. ■

Pioneer in Survivability—Terry L. Dougherty

by Michelle Campbell

Film director Cecil B. DeMille once said, "The person who makes a success of living is the one who sees his goal steadily and aims for it unswervingly. That is dedication." In today's fickle society, such devotion is rare. Yet, the survivability community owes many thanks to a man whose nearly unparalleled devotion to the Warfighter's safety motivated important technological advances directly benefiting today's aircrews. Terry L. Dougherty supported the Warfighter for over 25 years, playing a vital role in advancing cost- and life-saving countermeasures (CMs), particularly with the Threat Signal Processor-in-the-Loop (T-SPIL). Sadly, the Warfighter lost this passionate advocate on 14 October 2009; however, future generations will continue to benefit from the passion and skill that earned Terry the Fleet's highest respect. The JASPO is honored to posthumously recognize Terry L. Dougherty as one of its Pioneers in Survivability.

The Warfighter's Advocate

Terry was born in 1959 in Rochester, New York. He grew up in Spokane, Washington, with his brother and two sisters. From a young age, he loved math and taking things apart, ideal traits for a future engineer. In high school, when he had the opportunity to work on his math teacher's computer during free time, a specific career began to emerge. His natural love of math merged with his newfound interest in computers, and in 1982, Terry graduated from Washington State University with a BS in electrical engineering.

That same year, Terry accepted a position in the Junior Professional Engineering Program at the Naval Air Warfare Center Weapons Division (NAWCWD), China Lake, CA (then called the Naval Weapons Center). He loved the hands-on projects that supported a cause as important as protecting the nation's Warfighter. Whatever task he was working on, he was not merely earning a salary but rather striving to create a safer environment for those serving our country.

"Let's face it, civilians have it easy," Terry often said. "We work all day and get to go home to our families at night, safe and sound. The folks we support are at war, far away from home and family. The Warfighter is what motivates you to give them the best," and his best is precisely what Terry gave. [1]

Every aspect of his work reflected his commitment to bring servicemen and -women home safely by providing CMs that were more effective. "Protecting the Warfighter was his number one priority," said Jim Young, who worked with Terry on multiple projects for combat survivability evaluations and improvements on Navy and Marine Corps aircraft. Both Young and Randy Short, head of the Naval Air Systems Command (NAVAIR) Combat Survivability Division, described Terry as the first to respond if the Warfighter had any concerns. Moreover, Terry was able to pinpoint the core of the Warfighter's needs and selflessly support the person or group that could best resolve them. If a solution did not exist, Terry did his best to create one. "It was never about him," said coworker Bruce Heydlauff. "It was always about getting something better for the guys in the field."

As Terry's wife Keely so aptly phrased it, "Terry saw the big picture."

T-SPIL: A World-unique Facility

Terry's devoted work ethic, innovative engineering skills, and genuine concern for the Warfighter's survivability quickly demonstrated his aptitude for a Navy civilian career. He earned many

Terry L. Dougherty, presented with the Superior Civilian Service Award and Medal on 6 April 2009. U.S. Navy photo by Greg Turnbaugh.

commendations for his early service as a test engineer and a systems engineer on projects such as the Sidewinder AIM-9R, the Phoenix Missile APLUS Program, and the Terminal Infrared Guidance with Extended Range (TIGER).

Mike Hogan, who troubleshot components of APLUS and TIGER with Terry, remembers his practical, levelheaded approach to problem-solving. "He worked well under pressure," Hogan said, adding that Terry's easygoing and humorous nature made working under tight deadlines more enjoyable.

The SA-7 Strela 2 missile and canister, a man-portable surface-to-air missile that is potentially capable of downing an aircraft.

Terry's leadership skills quickly emerged as well. After serving as a technical lead, he accepted a position as head of the Advanced Signal Processing Branch in 1993 and became the driving force for improving signal processing tools and capabilities at NAWCWD. He soon developed a reputation as a leading expert in the field of electro-optical and infrared (IR) reverse engineering. During his time as Branch Head, Terry also chaired the Image and Signal Processing Network and participated in several foreign material exploitation efforts.

These experiences paved the way for one of Terry's most important influences in the field of aircraft survivability. In 1995, Terry began working with T-SPIL as a systems engineer, where he had an integral role in developing the remarkable T-SPIL facility. With the innovations of Terry and his teammates, including Heydlauff, John Channer, Bryan Ogilvie, Sue Oah, Dave Brewton, Dianne Krotter, Randy Mather, and Team Director Dennis McKinney, T-SPIL became a landmark program. [2]

Prior to the development of the T-SPIL facility in the late 1990s, developing CMs was costly and comparatively simplistic, requiring extensive funding for actual flight testing and evaluation. T-SPIL's unique ability to analyze threat anti-air missile response on fixed-wing aircraft and helicopters provided a means of obtaining threat data in previously unexplored areas. Time, money, and lives could be saved since T-SPIL's simulation and analysis ability was significantly more efficient than actual flight testing.

Many relied on Terry's air threat function expertise. The analysis projects he managed directly impacted the tactics and procedures of operational aircrews. As a result, T-SPIL has aided against enemy weaponry, such as Man-Portable Air Defense Systems (MANPADS), one of the most serious threats posed to US aircrews. [3] Another particularly significant improvement for US Navy and Marine Corps aircrews has been the decreased time required to field CMs, a life-saving development that will endure for generations. Terry also worked tirelessly to increase the number of threat system types available in the T-SPIL facility, providing credible analysis across a wider threat spectrum.

T-SPIL has relied on experts from many disciplines; however, as the systems engineer, Terry understood and orchestrated its various elements with a rare level of proficiency. His uncanny problem-solving ability allowed him to model complex mechanisms at a systems level, and then isolate and fix any problems. He was also able to predict how T-SPIL would respond during the critical moments of closing the loop. "I had never worked with anyone who had this ability," McKinney said. "He had a sixth sense about these things." With such expertise and excellent leadership ability, it was no surprise when Terry became Director of the Threat IR Weapons Office in 2002, a position he held for seven years.

Following his successful work on T-SPIL, Terry served as the technical lead and systems engineer for a team that leveraged the knowledge acquired from T-SPIL to develop the Rolling Airframe Missile Signal Processor-in-the-Loop (RAM SPIL). He and his team, including McKinney, Channer, Ogilvie, Mather, Oah, Krotter, Joe Lindula, Doug Philbrik, Allen Robins, Phil Surprenant, and Wayne Fiebick, developed RAM SPIL components whose technology extends to other missile programs as well. [4] Channer noted with appreciation Terry's approachable leadership style during the development process. "Friendly but in charge," Channer explained. "I could approach him with any technical problem." Many coworkers echoed this sentiment throughout Terry's career.

During the development of these facilities, Terry also supported other projects, providing technical consultation to the Federal Bureau of Investigation and the National Transportation Safety Board during the Flight 800 investigation. Terry also assisted with the Joint Strike Fighter and Standoff Land Attack Missile programs.

Family, Team, and the Warfighter: The Big Picture

Terry's expertise in CM effectiveness analysis using threat signal processor-based modeling and simulation made him invaluable in his line of work. However, his personal interest in mission effectiveness and the Warfighter's well-being is what earned him such high respect among the Fleet. The Fleet often sought his advice, and Terry was happy to oblige, going to squadron ready rooms to discuss threat system reactions and speaking with dignitaries about T-SPIL's practical applications and capabilities. He dedicated countless hours during his off time, working, as Major Kristian Pfeiffer described, "hours similar to the squadrons preparing to deploy." He was often the first to arrive at work and the last to leave.

"Terry became the trusted resource in NAVAIR regarding IR threat and availability. PMs [Program Managers] and Commanders in the United States Marine Corps…[were] comfortable basing acquisition and tactical decisions on his results," said Lieutenant Colonel Christopher J. Mattei. "Everyone you talk to in the field knew the quality of his work."

"It is one thing to be well-respected inside the test community. I believe this to be achievable by most," remarked Major Jeff Sykes. "However, to be well-respected and sought after for advice in the Fleet...well, now you're something special."

In 2009, Vice Admiral David Venlet, NAVAIR Commander, presented Terry with the Superior Civilian Service Award and Medal. This honor is the Navy's second highest award for civilians and recognizes exceptional leadership and service to the Warfighter. Following Terry's nomination, testaments of his personal influence on the Fleet poured in, praising his generosity, integrity, and work ethic.

The Superior Civilian Award crowned a career brimming with accolades. Beginning early in his service, Terry earned many team awards and numerous letters and certificates of appreciation. In 2003, Terry also earned the Dr. William B. McLean Award for his technical and systems engineering expertise in developing both the T-SPIL and RAM SPIL facilities. He also authored several published reports. Yet, throughout his career, Terry remained humble, acknowledging the crucial role of strong, cohesive teamwork. "Team is what matters," Terry said as he accepted the Superior Civilian Service Award, "a strong core team who view the Warfighter as the main reason we're here." [4] He also credited his family for the contributions they made for the cause of supporting the Warfighter.

Terry's appreciation of his family, friends, coworkers, and community is evident. One only has to look at pictures of him holding his children, laughing with his friends on the lake, or coaching a youth basketball team to see the joy they brought him. Described as playful, genuine, and thoughtful, Terry spent the majority of his time helping others. He volunteered often, coaching youth sports for many years and regularly dedicating time to his church. "He believed in picking something to focus on and committing," his wife said. Terry also made room for two dearly loved hobbies: basketball and aquatic sports, especially jet skiing. In fact, he would round up players for a game of basketball even while on business travel.

When asked how Terry's devotion to the Warfighter had influenced his family and friends, his wife quickly responded with examples of how he had put faces to those serving our country. He invited servicemen and women to his family's home for barbeques and always described his work as a way to ensure the Warfighter came home safely. "When you say 'I build missile parts,' for example, it's impersonal, but when you say 'I go to work to save the Warfighter,' it personalizes things," his wife Keely said. "With Terry it was about those guys' lives."

"It was good to see someone dedicated to a cause that important," McKinney remarked. "I think he inspired us all that way."

Terry's dedication to support and personalize the Warfighter has saved the lives of many American fighting men and women. In 2010, he was posthumously awarded the Bill Goodell Award for dedicated service to the infrared countermeasures community. Plans are in progress to name a new laboratory at NAWCWD after Terry. "After three plus years of working with Terry, he has earned my unconditional loyalty and utmost respect," said Pfeiffer. "I am not exaggerating when I say I am a better, safer pilot because of my interaction with Terry." One could not hope to receive a higher compliment. ■

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Analyzing Countermeasures with Real-time, Complex Scene Simulation

by Michelle Campbell

From the early 1970s to the late 1990s, infrared (IR) anti-aircraft missiles such as Man-Portable Air Defense Systems (MANPADS) were responsible for almost half of all combat aircraft losses worldwide. [1] During Desert Storm alone, MANPADS caused 56% of kills and 79% of damage to Allied aircraft. [2] As enemy access to MANPADS has steadily increased over the past two decades, so has the modern warfighter's need to possess effective countermeasure (CM) tactics. However, providing successful CMs is possible only through a complete understanding of the threat weaponry facing US aviators. Currently, a unique facility known as the Threat Signal Processor-in-the-Loop (T-SPIL) at the Naval Air Warfare Center Weapons Division (NAWCWD) in China Lake, CA, is enhancing the ability to analyze how threat missiles react in various scenarios. The real-time, complex scene simulation technology that T-SPIL supplies, coupled with real optical scene convolution hardware, is providing important tactical insights that are helping save warfighters' lives.

T-SPIL provides the aircraft survivability equipment (ASE) community with a credible means of collecting realistic threat performance data due to two crucial components—real time operation, and actual threat weapon signal processing electronic hardware in its entirety. Thus, T-SPIL can uniquely analyze threat anti-air missile track, guidance, and counter-countermeasure (CCM) response against fixed-wing aircraft and helicopters by using numerous tools—such as detailed, real-time, three-dimensional (3D) aircraft and CM models; detailed missile six-degree-of-freedom (6-DOF) aerodynamic flight models; actual threat signal processing electronics; and the NAWCWD-patented Real-time Optical Scene Convolver (RTOSC).

Prior to T-SPIL, it was virtually impossible to construct and operate a complex scene injection based simulation in real time for electro-optical missiles. The effort to create this simulation ability emerged from NAWCWD's earlier, successful development of the Precision Imaging Strike Technology Integration Laboratory (PISTIL) and the Sidewinder imaging Air Intercept Missile 9R (AIM-9R) weapon.

The Heart of T-SPIL: The Real-time Optical Scene Convolver

Unlike other hardware-in-the-loop (HWIL) simulators, which use actual seeker optics, T-SPIL is based on the RTOSC—a revolutionary invention. The RTOSC employs optical convolution of a computer-generated scene with seeker spatial impulse response functions. "Real-time digital scene optics convolution allows reticle-scanned or optically blurred detectors to be simulated with complex scenes and backgrounds in a laboratory setting," said Bruce Heydlauff, one of the RTOSC's inventors. "This missile simulation requires no moving parts and is limited only by the graphics computer's ability to generate accurate target and background scenes for the simulation flight path."

Whereas an actual seeker requires hardware components, such as the gimbal and detectors, T-SPIL combines a high-fidelity digital gimbal model with an optics and detector model using a graphics computer and the RTOSC. The RTOSC performs real time convolution within each detailed scene image at a rate that minimizes unwanted simulation artifacts, such as signal noise. The optics and detector impulse responses are captured in a digital "mask," which is employed during the convolution process.

Heydlauff describes the rendered scene as a "virtual reality for the missile sensor." The missile's processing unit is tricked into believing that the detector signal is coming from its own IR sensor/seeker as it searches for and tracks a target. Changes in aspect and orientation of the scene objects are updated in real time to correlate with what the seeker would see if the missile were actually flying. The actual threat hardware is operated in real time as well, which is necessary to capture realistic electronics performance behavior.

During the simulation, the missile responds with two fundamental command signals, as it would in actual flight—the platform precession and guidance commands. The precession command signal is fed to the high-fidelity digital model of the seeker platform, which forces it to continually point at the currently tracked target. The guidance command signal is sent to the high-fidelity digital 6-DOF model, which causes maneuvering of the missile while in simulated flight.

Throughout the process, analysts observe missile performance behavior, thus noting the missile's target tracking and airframe guidance responses. Instantaneous feedback gives testers the opportunity to conduct a run-by-run analysis of the weapon's performance and CCM reactions.

Simulation and Analysis Capabilities

Over 2,000 threat missile engagements can be conducted for each of the installed threat systems in an eight-hour period. In especially large studies, the simulator can operate around the clock unattended, with short breaks for analysts to assess intermediate results. Such a high number of test runs permits a quick turnaround time for resolving the safety concerns of those currently operating aircraft in the field. For example, the warfighter may ask: From how far away can a threat missile lock onto an aircraft? How effective are the planned CMs? If the aircraft is moving at a certain velocity and a flare is deployed, how effective is the CM? If the planned CM does not work, where will the missile generally impact the aircraft?

Analysis information at the conclusion of each simulation effort includes hit plots, impact distributions, Time Space Position Information (TSPI), and individual engagement video output files (which allow analysts to view the images fed to the threat hardware). Post analysis also incorporates a visualization tool that portrays a controlled, simulated view of each engagement; seeker and airframe pointing vector data; missile state data; and weapon flight trajectory information. Comprehensive analyses can be performed by using multiple altitudes and speeds. Additionally, the use of actual missile hardware allows for real-world influences (such as electronic signal processing noise and electronic circuit nonlinear response) that result in realistic, non-deterministic simulator behavior.

The wide variety of possible target and attack scenarios that can be generated by the IR scene imaging computers provides numerous investigation opportunities for CM designers, analysts, tacticians, aircraft structural and materials engineers, and aircrews. Since such a high number of runs is possible in a given time period, analysts can rerun a scenario as many times as necessary to evaluate data (such as the amount of intercept dispersion present for different missiles in the same scenario) or to calculate possible outcomes using Monte Carlo distribution.

Model Validation

Since T-SPIL's initial development process, the team has validated model accuracy with test data collected from laboratory measurements and has favorably evaluated performance against aircraft and countermeasure data. When applicable, validation has also included successful comparison of T-SPIL engagements to those completed in field testing using captive threat seeker vans.

The T-SPIL facility encompasses an extensive library of aircraft and flare models. These detailed 3D models incorporate IR airborne measurements, atmospheric attenuation and solar effects, material paint properties, engine plumes, and aerodynamic heating elements. T-SPIL also employs expendable, high-fidelity CM models. "We're using the best models available," said Dennis McKinney, T-SPIL Team Director and one of the inventors of the RTOSC.

Cost Savings

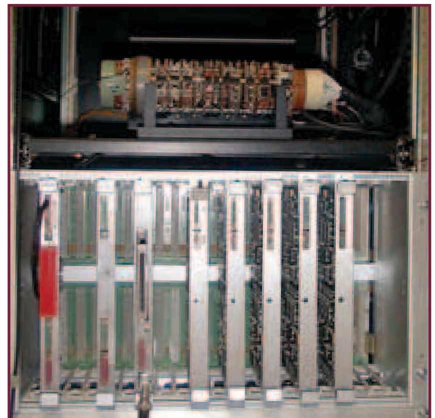
T-SPIL's sophisticated analytic capabilities reduce testing costs and allow researchers to plan and predict testing outcomes in open-air test environments. This type of planning and prediction works for both captive seeker testing and live fire events. As an example, simulation *via* T-SPIL costs less than $3 per engagement, as opposed to more than $200 for captive seeker simulation and significantly more for each live fire event.

T-SPIL offers other financial savings as well. Whereas seeker parts eventually wear out, the RTOSC allows a "second life" for the hardware, since the convolver does not require the type of components that tend to degrade or fail.

Today's T-SPIL facility contains the third generation of RTOSC hardware configuration, which provides higher performance, increased reliability, and lower cost than previous generations.

Challenges in Development

In the mid to late 1990s, Larry Rollingson presented the concept for T-SPIL to fellow PISTIL team member Bruce Heydlauff. Approximately six months later, Heydlauff, along with McKinney and John Channer, developed and demonstrated the RTOSC algorithm.



A threat signal processing unit and T-SPIL hardware.

Other prominent T-SPIL team members include Brian Ogilvie, who along with Channer designed the RTOSC hardware; Sue Oah, who created the circuit board designs; Terry Dougherty, who executed the overall T-SPIL systems engineering; and Dave Brewton and Dianne Krotter, who assembled the system and circuit boards. [3]

Developing T-SPIL was not without its challenges. The high-speed calculation requirements necessary to run the RTOSC in real time were originally considered impossible by others in the missile simulation field. The greatest challenge facing Heydlauff, McKinney, and Channer was translating the IR image, in real time, into what the detector would see if the missile were actually operating. Another challenge was creating a satisfactorily accurate model, which remains an ongoing effort to keep scene realism in line with ever-improving technology.

T-SPIL's technology demonstration was funded by the Office of the Test Director (now the Center for

The official T-SPIL logo.

Countermeasures), an Office of the Secretary of Defense Testing and Evaluation (T&E) Directorate at White Sands, NM. Full-scale development funding for T-SPIL was provided by the Central Test and Evaluation Investment Program (CTEIP) Crossbow Committee, which is now the Threat Systems Working Group.

"We filled an important niche in simulation technology that didn't exist," McKinney said. "This niche allows a large volume of high fidelity simulation at low cost." In the true spirit of JASPO's slogan—"Survivability Today and Beyond"—T-SPIL will continue to equip the warfighter with life-saving countermeasure tactics that will endure for decades. ■

References

1. Michael Puttre, "Facing the Shoulder-Fired Threat," *The Journal of Electronic Defense* (April 2001).
2. GlobalSecurity.org: Military, "*Man Portable Air Defense System (MANPADS)*," *http://www.globalsecurity.org/military/intro/manpads.htm*.
3. Cliff Lawson, "T-SPIL Exploits Threat Missile Hardware," *The Weaponeer* (December 9, 1999).

Competitive Prototyping for Infrared Countermeasures

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and were chosen from the Army, Navy, and Air Force to ensure representation from all Services. The panel was chartered to provide an independent assessment. Given the anticipated push-back of industry and the large number of stakeholders involved within the Services, a panel such as the one assembled for CIRCM was critical to maintaining the credibility of programmatic decisions based on the risk assessment.

Competitive prototyping test results were fed to the Gray Beard panel along with briefings from the vendors describing their specific architectures and designs.

The risk assessment was developed against the time required to mature these designs to a Technology Readiness Level (TRL) of 6. Designs were broken up into critical technology elements for performance, such as energy on dome, hand-off timing, pointer/tracker accuracy, *etc*. Each element was assessed for maturity, and the time that it required to reach TRL 6.

Lessons Learned

Competitive prototyping *informs the acquisition strategy by placing the program in the correct phase of the acquisition process*. This is critical in preventing cost overruns and schedule slips caused by immature technology.

No company has ever stayed in business by saying "we can't do that," and it is the responsibility of the Program Manager to help determine design maturity before the program enters the acquisition process without simply relying on industry marketing briefs. Care should be taken in defining the environment for testing to ensure that all tests are conducted in a realistic environment. TRL 6 = representative prototype in a relevant environment for MS B.

Assessment of risk based on prototype hardware test data collected in a relevant environment is much more credible than analysis alone. Further, the use of an independent multi-Service SME panel to perform a risk assessment of competing designs minimizes challenges to both results and any decisions based on those results.

Summary

Results of the competitive prototyping effort significantly changed the CIRCM acquisition strategy. The resulting program is now structured to allow time to mature designs, develop modular systems architectures, and understand all risks before proceeding to the next phase of development. This has laid a foundation to achieve a CIRCM solution for the warfighter that is effective from the standpoints of both cost and operations. ■

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OCT

15th Annual Expeditionary Warfare Conference
4–7 October 2010
Panama City, FL
http://www.ndia.org/meetings/1700/Pages/default.aspx

Aircraft Fire Protection/Accident Investigation Course
4–8 October 2010
Miamisburg, Ohio

Aircraft Fire Protection and Mishap Investigation Course
4–8 October 2010
Miamisburg, OH
http://www.afp1fire.com/course.htm

26th Space Simulation Conference
18–21 October 2010
Annapolis, MD
http://www.spacesimcon.org/

NOV

USSTRATCOM Space Symposium 2010
2–3 November 2010
Omaha, NE
http://www.afcea.org/events/preregister.cfm?event=USSTRATCOM+Space+Symposium+2010

Aircraft Survivability Symposium
2–5 November 2010
Monterey, CA
http://www.ndia.org/meetings/1940/Pages/default.aspx

2010 Combat Vehicles Conference
8–9 November 2010
Dearborn, MI
http://www.ndia.org/meetings/1620/Pages/default.aspx

JASP Winter JMUM
15–18 November 10
Nellis AFB, NV

DEC

AAAA Unmanned Aircraft Systems Symposium (UAS)
13–15 December 2010
http://www.quad-a.org

JAN

West 2011
25–27 January 2011
San Diego, CA
http://www.afcea.org/events/preregister.cfm?event=West+2011

FEB

JASP Subgroup Meeting
1–3 February 2011
TBD

2011 Tactical Wheeled Vehicles Conference
6–8 February 2011
http://www.ndia.org/meetings/1530/Pages/default.aspx

MAR

JASP OAG/SAG Program Review Meeting
4 March 2011
Washington, DC

27th Annual National Test and Evaluation Conference
14–17 March 2011
Tampa, FL
http://www.ndia.org/meetings/1910/Pages/default.aspx

JASP Spring PMSG
29–31 March 2011
TBD

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