AIRCRAFT SURVIVABILITY

Published by the Joint Aircraft Survivability Program Office

JOINT AIRCRAFT SURVIVABILITY PROGRAM

SPRING 2011

VULNERABILITY REDUCTION

Aircraft Survivability is published three times a year by the Joint Aircraft Survivability Program Office (JASPO) chartered by the US Army Aviation & Missile Command, US Air Force Aeronautical Systems Center, and US Navy Naval Air Systems Command.

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

To order back issues of the ASnewsletter, please visit http://www.bahdayton.com/surviac/inquiry.aspx.

On the cover:
An AH-64D conducts a combat patrol in support of Operation Enduring Freedom.

Table of Contents

Onboard fires are the main damage mechanism responsible for air system losses. Aircraft fuel and hydraulic systems and their adjacent dry bays are particularly vulnerable during combat, since the effectiveness (lethality) of modern conventional weapons is directly proportional to ignition capability. Furthermore, peacetime and civilian operations are also affected by unanticipated design flaws and mishaps resulting in fires.

United Technologies Research Center and the US Army Aviation Applied Technology Directorate developed and demonstrated an affordable, lightweight integrally armored helicopter floor. Using the Sikorsky H-60 platform architecture, the floor demonstrated ballistic protection from the 7.62 x 39 millimeter (mm) Armor Piercing Incendiary round at 44% lighter weight than the baseline floor/armor system. The integrally armored floor also maintained the structural functions of the current floor.

Helicopters are particularly susceptible to threat impact from small arms and unguided munitions due to their inherent low-and-slow flight parameters. It is often not obvious to aircrew when they are under fire. A large amount of projectiles may be expended, with the attack occurring over a considerable period of time until the craft may actually be impacted by the enemy. It would be of immense value if the pilots of these craft could be quickly alerted to incoming fire so that they may take evasive maneuvers.

The JASP is pleased to recognize Mr. John J. Murphy, Jr. for Excellence in Survivability. John is Technical Director for the Air Armament Center, 46th Test Wing, 46th Test Group, Aerospace Survivability and Safety Operating Location at Wright-Patterson AFB, Dayton, OH. For 25 years John has been a leader in advancing and applying technology to predict, evaluate, and improve combat survivability of US flight vehicles. John graduated from the University of Cincinnati in 1986 with a Bachelor of Science degree in Mechanical Engineering. He followed that with a 1991 Master of Science degree in Mechanical Engineering from the University of Dayton.

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

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 Editor
Daniel Eckroad

Newsletter Design
Tammy Black

Illustrations, Cover Design, Layout
Tammy Black

Distribution Statement A:
Approved for public release; distribution unlimited, as submitted under NAVAIR Public Release Authorization 11-198.

by Dennis Lindell

Joel Williamsen Receives NASA Award

The National Aeronautics and Space Administration (NASA) selected Dr. Joel Williamsen to receive the NASA Engineering and Safety Center (NESC) Leadership Award. The award was presented 16 November at the Marshall Space Flight Center (Huntsville, AL). The citation reads:

"In recognition of outstanding leadership and technical insight into the NASA Engineering and Safety Center micrometeoroid and orbital debris assessment (M/OD) activities."

The award is based on four NASA tasks Joel has supported since 2003, including: Columbia Accident Investigation (2003), M/OD Risk Assessment Program Validation (2006), Orion M/OD Protection Assessment (2008), and International Space Station M/OD Protection Evaluation (2010, currently underway).

Joel is one of our own and we congratulate him on a job well done.

NASA ESC Chief Engineer (right) and Chief Astronaut bestowing the award on Dr. Williamsen

Larry Eusanio: In Appreciation

Larry Eusanio

With sadness, we note the loss of Larry Eusanio on 6 October 2010. His career in aircraft survivability was long, productive, and influential, beginning in 1956 and continuing until shortly before his death. He was recognized in recent years with two major professional awards. In 2004, he was presented the American Institute of Aeronautics and Astronautics (AIAA) Survivability Award for his achievements in the field of aircraft survivability. In 2007, NDIA presented him the Arthur Stein Award for outstanding contributions in Live Fire Test and Evaluation (LFT&E).

He began his career at Cornell Aeronautical Laboratory (later called Calspan) in Buffalo, NY, where he worked on a variety of survivability and effectiveness programs. One of his first innovations was the development of a digital simulation to conduct end game studies of the Eagle missile warhead-fuze combination. This was one of the first digital end game models, and it served to speed design trade studies. Prior to that time, end game studies were done manually using physical scale models to work out the geometry.

In another early study (1964), Mr. Eusanio led a project to determine the effectiveness of conventional munitions in realistic environments such as vegetation and snow. Up until that time, effectiveness estimates were based on a bald earth. These models and data later were used by the Joint Technical Coordinating Group on Munitions Effectiveness (JTCG/ME) to produce the Joint Munitions Effectiveness Manuals (JMEM) for this type of weapon system, which were urgently needed for the Southeast Asia conflict.

In the 1970s and 1980s, his primary emphasis was on the effectiveness of countermeasures as a function of various flight profiles. His trade analyses led to the identification of optimal countermeasure suites, tactics, and flight profiles for Army and Air Force standoff aircraft such as Guardrail, Quick Fix, and Joint Stars. The Joint Stars Program Manager unofficially gave him credit for saving the program from early cancellation due to Office of the Secretary of Defense (OSD) concerns for platform survivability.

In 1989, Larry Eusanio moved to the Institute for Defense Analyses (IDA). It is fitting that he was hired, in part, based on a strong recommendation from Arthur Stein, an early pioneer of the aircraft survivability discipline. Mr. Eusanio led the Air Systems LFT&E project for manned aircraft, anti-air weapons, missile defense systems, Joint Live Fire (JLF) of aircraft, and the Joint Aircraft Survivability Program. In 1991, Larry Eusanio co-authored a briefing to the National Research Council's Committee on Weapons Effects and Airborne Systems concerning the applicability of aircraft survivability test and evaluation methodologies for the LFT&E of such aircraft as the C-17 and F-22.

Mr. Eusanio provided analytical support for most of the aircraft and anti-aircraft programs conducted to date under LFT&E statutory requirements. A number of these test and evaluation programs have resulted in substantial improvements to system survivability through changes to aircraft design or operational employment. He authored, co-authored, or made major contributions to more than seventy publications in survivability and effectiveness. He took a special interest in initiatives to improve the state-of-the-art of LFT&E, to place greater emphasis on the evaluation of human casualties, to integrate Battle Damage Assessment and Repair into LFT&E, and to integrate LFT&E with related safety tests.

Throughout his professional life, Mr. Eusanio provided sustained analytical contributions to improve the survivability and effectiveness of US military aircraft and weapon systems. These contributions were visible at high levels in OSD and Congress and addressed all classes of manned aircraft currently in the defense inventory and acquisition process.

Most importantly, though, Larry Eusanio was loved and respected by all who worked with him. He was fair in his analyses, even-tempered in his demeanor, and strong in his advocacy of aircraft survivability. He chose to stay involved in his work even as he suffered declining health, and he has left us with a wealth of personal memories and a legacy of analytical contributions.

Bill Keithley, Long-Time Aircraft Survivability Practitioner, Dies


Bill Keithley

On 16 November 2010, William (Bill) Keithley, an aircraft survivability specialist for almost four decades, passed away due to complications from an infection. Bill was a former Air Force sergeant and decorated Vietnam veteran who spent most of his civilian career working at the Philips Army Airfield at Aberdeen Proving Ground, MD. There, he worked as an aircraft mechanic and inspector for Ross Aviation for 6 years; as an engineering technician, senior test director, and range manager for the US Army Ballistic Research Laboratory (and later the US Army Research Laboratory) for 27 years; and finally as an aviation test and analysis support contractor for the SURVICE Engineering Company for 7 years.

Bill was known as a practical, nuts-and-bolts expert on both foreign and domestic rotorcraft systems, particularly propulsion systems, rotor drives, and rotor blades. He will be greatly missed by his family, long-time coworkers, and those who continue in his work of making helicopters safer and more survivable for American warfighters.

Joint Aircraft Survivability Program (JASP) Changes

New Army Principal Member Steering Group (PMSG) Co-Chair

John Kamadulski, who was the Army JASP Principal Member since August 2003, passed the baton to Don Hubler in July 2010. In addition to serving on the PMSG for 7 years, John led the


COL John Leaphart, PM ASE recognizing John Kamadulski at John's retirement party

Continued on page 8

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

The Joint Combat Assessment Team (JCAT) continues its tradition of providing aircraft operational support to the warfighter. Now that the emphasis of warfighting efforts have shifted to areas of operation in Afghanistan, the in-theater JCAT presence in Iraq officially ceased upon the departure of LCDR Dave Schubkegel from Baghdad on 19 August 2010. The JCAT (Forward) will continue to track and capture available data related to aircraft battle damage incidents occurring in Iraq *via* the cooperative effort by the Army Combat Action Badge personnel deployed in the area of operations there.

The Operation Enduring Freedom JCAT experienced a very busy late summer and early fall as the traditional fighting season in Afghanistan drew to a close. A JCAT record of five battle damage assessments were conducted in one day by Maj Mark Friedman, US Air Force, during a peak period in late August in RC-South. A catastrophic engagement in late July resulted in the loss of an AH-1 Cobra helicopter in RC-Southwest. CDR Craig Fehrle and LT Oral John responded to the incident and conducted an initial assessment. The aircraft wreckage and associated components were recovered and returned to Camp Leatherneck/Bastion where a thorough assessment was conducted. After sifting through the wreckage and debris, an exterior panel exhibiting telltale signs and critical fragments were identified and collected. The weapon employed against the aircraft was correctly assessed by the JCAT and later positively identified *via* metallurgical analysis of the recovered fragments. While tragic in outcome, this event once again substantiates the value and rigor of the training JCAT members receive prior to deployment and the ability of JCAT to provide accurate recognition and analysis of battle damage discriminators to provide actionable feedback to the warfighter command element.

Continued on page 31

Survivability Assessments—The Fire Prediction Model (FPM)

by Jaime Bestard

Onboard fires are the main damage mechanism responsible for air system losses. Aircraft fuel and hydraulic systems and their adjacent dry bays are particularly vulnerable during combat, since the effectiveness (lethality) of modern conventional weapons is directly proportional to ignition capability. Furthermore, peacetime and civilian operations are also affected by unanticipated design flaws and mishaps resulting in fires.

Traditionally, fire risks have been identified by subject matter experts and educated trial and error during Live Fire Test and Evaluation (LFT&E), Operational Test and Evaluation , and actual aircraft operation in peacetime and combat. In addition, vulnerability analyses have relied heavily on "best" guesses based on coarse modeling and simulation (M&S) and/or costly test and evaluation (T&E). Therefore, a credible, fast-running, physics-based fire modeling capability has been required for system design and optimization, survivability assessments, and LFT&E support. Such a capability identifies and reduces fire risks and decreases the costs of LFT&E.

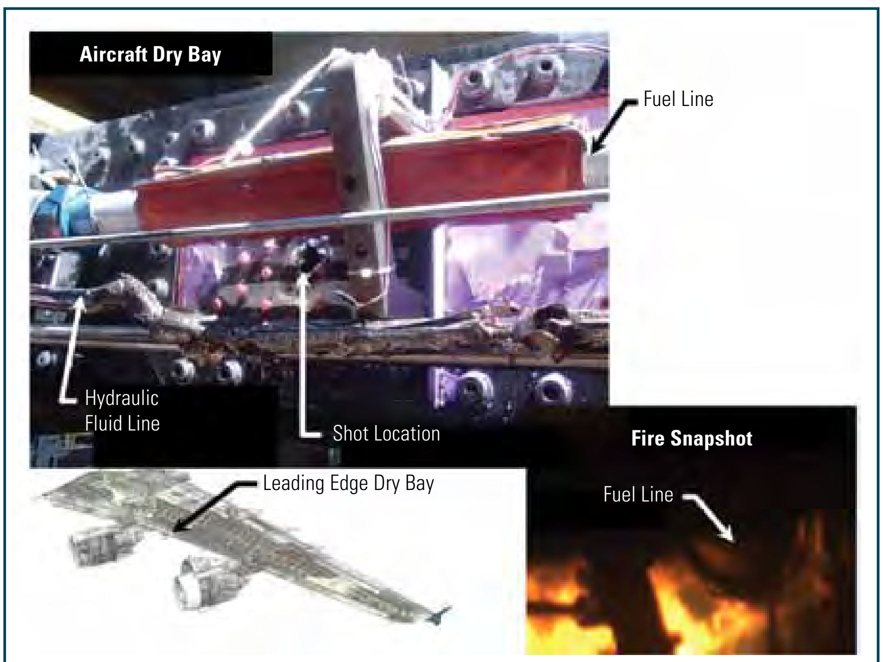

Figure 1 Effects of an aircraft dry bay fire

Development

The Joint Aircraft Survivability Program (JASP) and its predecessor, the Joint Technical Coordination Group for Aircraft Survivability, have sponsored the development of the Fire Prediction Model (FPM) since 1991. Originally known as the Dry Bay Fire Model (DBFM), the model provided guidance on the realism of surrogate targets used in place of the actual vehicle during the C-17 LFT&E program. The original model was an algorithm capable of simulating the ignition of fuel sprays by armor piercing incendiary (API) projectiles. Since then, the model has evolved to simulate not only fuel spray ignition, but also ullage explosions and fire sustainment and suppression while taking into account various ignition sources (*e.g.*, ballistic threats), target configurations, and environment and encounter conditions. An alternate Ground Vehicle Fire Model (GVFM) was developed and combined with the DBFM in 2003 to form the FPM.

Model Overview

The FPM performs simulations of the events during penetration of a single threat through a vehicle and impacting a container holding a flammable fluid (*e.g.*, a fuel tank or pressurized line with either fuel or hydraulic fluid). This unique capability distinguishes FPM from models outside the survivability discipline, where the latter concentrate primarily on the sustained combustion phase of fires and do not address ballistic-initiated fires.

FPM contains a library of generic threats to combat aircraft (including API and high explosive incendiaries or HEI) and other ignition sources such as sparks and hot-surfaces (from engine and heating components). The model also provides fluid properties for standard JP-4, JP-5, JP-8, and diesel fuels and MIL-H-5606 and MIL-H-83282 hydraulic fluids and allows the user to enter custom fluids into simulations. Fire extinguishing is also included in simulations and the model has an extensive library of agents available.

FPM analyses include complex mechanisms that affect fire behavior, such as hydrodynamic ram (HRAM), fluid spray geometry, flow and migration, and combustion products. In addition, the model outputs probabilities of ignition and key time

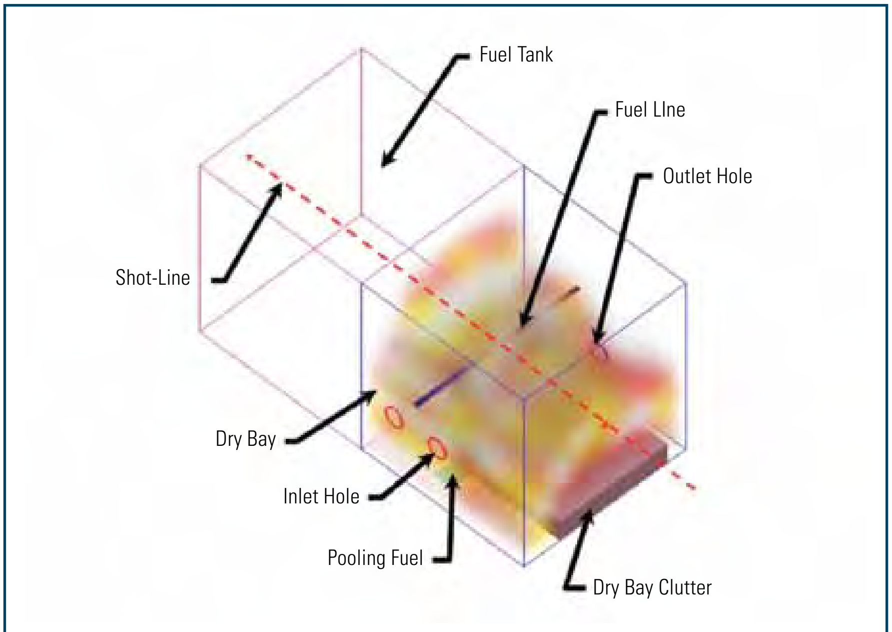

Figure 2 Typical FPM simulation

series, such as temperature, heat flux, species concentrations, and oxygen and fuel vapor densities.

Uses and Users

The FPM has been used for test predictions and design engineering within the aircraft, ground vehicle, and threat lethality communities. Various organizations have supported predictions over a wide range of platforms. Principal users of the model have included the SURVICE Engineering Company, Lockheed Martin, the Northrop Grumman Corporation, The Boeing Company, the Naval Surface Warfare Center, the Army Research Laboratory, and the B-1B, CH-53K, C-27J, C-5, C-17, and P-8 programs.

The model supports key design areas within the survivability discipline, including test planning, vulnerability assessments, and system design. Model uses in test planning and evaluation include shot-line selection, pre-test predictions, post-test analysis, and the identification of required instrumentation for test data collection. Vulnerability assessments benefit from physics-based ignition probabilities, descriptions of the fire environment, and the identification of heat fluxes and durations affecting structural strength and thereby kill level definitions.

Ongoing and Future Efforts

During 2010, the FPM underwent a major restructuring (modularization) effort. Previous versions of FPM were structured around different fire scenarios, *i.e.,* dry bay fires, spray fires, and ullage fuel-air explosions. These different scenarios required redundant routines for threat penetration, incendiary function or fragment flash characterization, spray characterization, and fire initiation, among others. As these routines had to be modified, the developer had to go through the code and ensure that changes were replicated throughout similar routines in the model. The new FPM v4.0 has been restructured around the various stages of fire, *i.e.,* threat penetration and characterization, ignition, growth and sustainment, and suppression. Supporting modules will ensure seamless interaction with other system-level tools (*e.g.,* COVART) and projectile penetration models (*i.e.,* FATEPEN and ProjPen). Furthermore, modularization will streamline model development and verification and validation (V&V) efforts, thereby reducing costs and minimizing programmatic risks.

A parallel effort to the FPM modularization has been the development of enhanced fragment flash characterization techniques and a corresponding fragment flash model. Previous versions of FPM were limited by the inability to predict front-face (impact-side) flashes (a survivability-community deficiency). As such, flashes that lingered with sufficient energy and duration on the dry-bay side of fuel tanks had a high potential of igniting the fuel spray and causing sustained fires. The model was not capable of predicting such events. Furthermore, previous ballistic testing performed to characterize the magnitude of such flashes predated digital high-speed video. For that reason, the Aerospace Survivability and Safety Operating Location (USAF AFMC 46 TG/OL-AC) and the Aeronautical Systems Center at Wright-Patterson Air Force Base have been involved in a ballistic testing effort to characterize the magnitude of fragment flashes and produce enhanced flash characterization routines applicable to FPM and COVART and replacing the current methodologies.

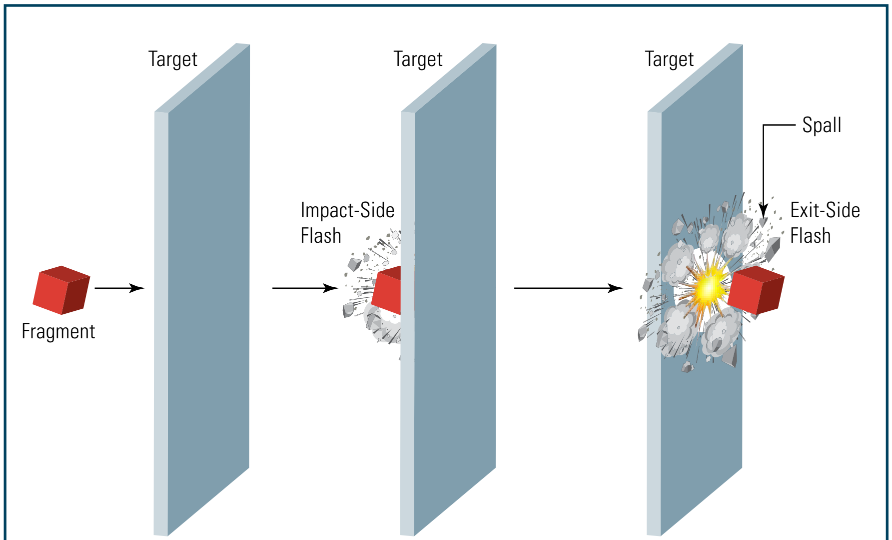

Figure 3 Fragment flash phenomena

Future FPM enhancements include a full V&V effort of the new FPM v4.0 and subsequent versions including enhanced flash characterization and the interface with standard penetration algorithms. Additionally, the survivability community has identified deficiencies in characterizing HRAM that possibly affect FPM predictions due to its effect on fluid spray and spurt characteristics and timing. Reviewing HRAM characterization methodologies and enhancing engineering-level models of this damage mechanism will benefit fire and damage predictions. Finally, one of the requirements for FPM is fast runtimes and this is accomplished by simplifying geometries to rectangular tanks, bays, and clutter. Model users have expressed interest in a seamless interface with common modeling tools (*e.g.*, BRL-CAD and FASTGEN) to streamline their fire modeling process. The FPM configuration control board has included these concerns in the model development roadmap.

Summary

Fire damage has been identified as the major damage mechanism involved in the loss of combat vehicles. Therefore, fuel and hydraulic systems remain the focus of survivability assessments, vulnerability reduction (including ullage and dry bay protection), and countless T&E and M&S efforts. To support these efforts, the JASP has supported the development of a fire modeling tool in the form of FPM. This model has been used for various purposes within the system acquisition and survivability communities. This JASP tool has provided reductions in the costs of major LFT&E programs and has supported the identification of vulnerabilities in new and operational systems. Its development has pushed the state-of-the-art in combat survivability fire modeling and ongoing efforts will minimize future risks of fast-paced acquisition programs and war-fighter survivability projects. ■

References

1. Aircraft Ballistic Initiated Fire Modeling. Dexter, Ronald M. and Pascal, Andrew. 2005. Austin, Texas : American Institute of Aeronautics and Astronautics, 2005. AIAA 2005-2332.
2. Ball, Robert E. 2003. The fundamentals of aircraft combat survivability analysis and design. Reston, Virginia: American Institute of Aeronautics and Astronautics, 2003. 1563475820.
3. Ballistic Fire Modeling and Simulation. Dexter, Ronald M. 2009. Palm Springs, California : American Institute of Aeronautics and Astronautics, 2009. AIAA 2009-2399.
4. Dexter, Ronald M. 2008. Fire Modeling with the Fire Prediction Model (FPM)—Application for Survivability Discipline. Aircraft Survivability. Spring, 2008.

News Notes

Continued from page 5

PMSG from March 2006 – April 2008. John retired from the US Army Aircraft Survivability Equipment (ASE) Project Manager's Office in September 2010.

Don Hubler, APM LCM

Mr. Don Hubler holds a BS degree in Mechanical Engineering from North Dakota State University and has been a civilian with the Army for over 34 years. He has been a member of the ASE Project Manager's Office since 1987, where he has worked on numerous ASE programs to include all Army legacy systems as well as Advanced Threat Infrared Countermeasures, Common Missile Warning Systems, and Suite of Integrated Radio Frequency Countermeasures. He has held positions as the Test Division Chief, Tech Division Chief, and Chief Systems Engineer within PM ASE. He is currently working on the AN/AVR-2B laser detecting set program. Mr. Hubler serves as the Assistant Project Manager for Laser Countermeasures.

Matt Crouch moves onto the Federal Aviation Administration (FAA)

Matt Crouch

After five years at the JASPO, first as the Vulnerability Reduction Deputy Program Manager (DPM) and then as Susceptibility Reduction DPM, Matt Crouch accepted a position at FAA Headquarters updating their Research & Development plan. His last day at JASPO was Friday, 22 October 2010.

Before coming to JASPO, Matt served as an Aerospace Engineer in the Utility Division of the Aviation Engineering Directorate at Redstone Arsenal, AL. Matt received his BS degree in Civil Engineering from the United States Military Academy in 1996. Before leaving active duty, he served in Iraq as a Black Hawk Maintenance Test Pilot with the 101st Airborne Division. While we hate to see Matt go, we wish him and his family all the best.

Ken Branham returns to JASPO

Ken Branham

CAPT Ken Branham, United States Navy (USN), finished a two year tour as the JASP Military Deputy Program Manager and Joint Live Fire/Aircraft Systems Joint Test Director in September 2009. Following a short sabbatical with the Institute for Defense Analyses, Ken "Mad Dog" Branham has returned to the JASPO. Effective Monday, 25 October, Ken is the JASP Vulnerability Reduction Deputy Program Manager. Please join us in welcoming Ken back to the JASPO. ■

Integrally Armored Helicopter Floor

by Connie Bird, Mark Robeson, and Alan Goodworth

United Technologies Research Center and the US Army Aviation Applied Technology Directorate developed and demonstrated an affordable, lightweight integrally armored helicopter floor. Using the Sikorsky H-60 platform architecture, the floor demonstrated ballistic protection from the 7.62 x 39 millimeter (mm) Armor Piercing Incendiary round at 44% lighter weight than the baseline floor/armor system. The integrally armored floor also maintained the structural functions of the current floor.

Requirements and Baseline

From the project's conception, the integrally armored floor (IAF) was required to provide ballistic protection from the 7.62 x 39 mm Armor Piercing Incendiary (API) round at service velocity, while still performing all of the functions of the current floor. The IAF was also required to weigh at least 33% less than the baseline floor/armor system using parasitic high hardness steel armor.

Since the H-60 platform architecture was used for this project, a baseline system of the current UH-60 floor with add-on high hardness steel armor was defined, depicted in Figure 1. Weight and thickness of the current floor (including features) and the steel armor were developed for comparison purposes. [1] Holes, shown in Figure 2, were developed in the armor protection to access features in the floor, such as seat posts and cargo tie down rings. However, these holes do result in significant unprotected floor area for typical add-on armor. Another important consideration is that the spacing of the I-beams beneath the floor requires an armor floor tile of at least 22” by 22” to span the distance between beams.

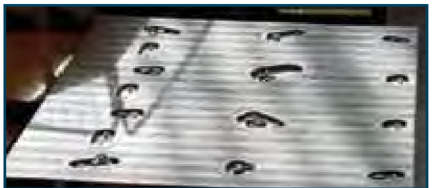

Figure 2 Production UH-60 Floor Panel with Attachment Features

Figure 3 Selected Floor Configuration with Integral Armor

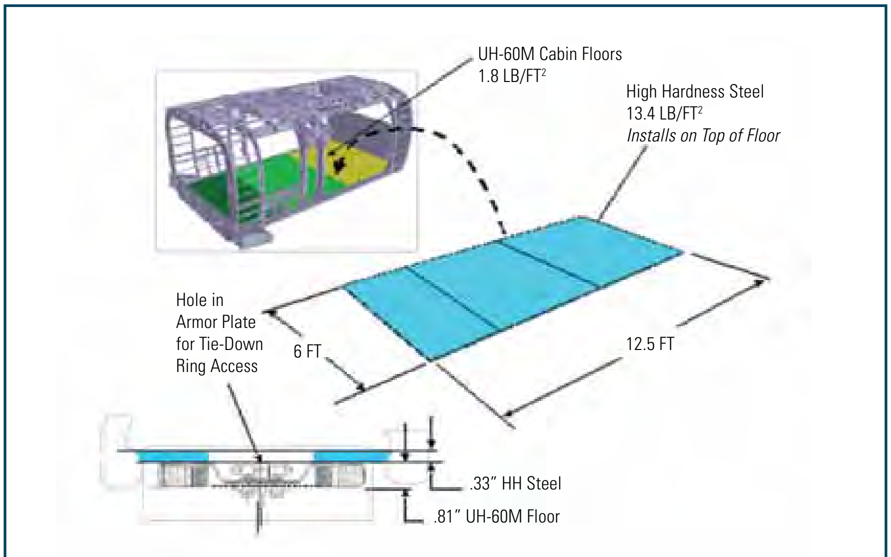

Figure 1 Baseline Floor/Armor System in UH-60 Cabin

In addition to the ballistic protection requirement, the IAF had to meet load bearing and durability requirements. Historically, the most difficult durability requirement is the pine box drop. A 200-pound (lb) pine box filled with rocks is dropped on one corner from a height of 15 inches onto an 18-inch by 18-inch section of the floor supported on two edges. Post impact, any resulting impression in the floor's top surface cannot exceed 0.3 inches in depth.

Configuration and Material Trade Studies

Design trade studies were conducted to develop an IAF design that affordably met or exceeded the 33% weight reduction goal. The design studies examined both variations in the floor geometry as well as different armor material systems.

Each candidate configuration integrated a hard armor layer into the lower portion of the floor and used it as a load-carrying member. Each configuration also used a common soft spall shield material at or near the top of the core stack. The selected design included a lightweight foam or honeycomb sandwich option as the top layer (Figure 3).

The hard armor layer material selected was a hybrid of Ceramic and Ceramic Matrix Composite (CMC). This material system uses a monolithic ceramic face panel with backing layers of CMC material. This formed a hybrid ceramic panel strong enough to carry the floor bending loads. This panel was backed by a layer of Dyneema®, a lightweight core material created depth to accommodate the seat pans, while front and back face sheets held the material stack together.

Material Optimization and Testing

Due to the floor configuration and material systems selection, a baseline material configuration was defined. Variations in the compositions and arrangements of the Ceramic/CMC hard layer were selected for fabrication, strength testing, and ballistic testing.

Two rounds of fabrication and ballistic testing were completed. The first round used 5-inch by 5-inch floor sections, and the second used 12-inch by 12-inch floor sections. The larger sections were each shot twice on 7-inch centers and each section stopped both rounds. Away from the holes caused by the projectiles, the Ceramic/CMC layer was intact after ballistic impact. The lightest configuration tested was selected as the final IAF configuration.

Ballistic Modeling and Simulation

Throughout the project, ballistic models were developed, improved, and refined. All simulations were produced using the LS-DYNA Explicit Finite Element code, and the models initially used all-Lagrangian representation. Even though the ceramic material was modeled using a Johnson-Holmquist ceramics damage model, the erosion of failed ceramic material was unrealistic. [2] There were similar problems with the penetrator portion of the bullet. The bullet was modeled using a Johnson-Cook material damage model. [3] The elimination of elements caused unrealistic peaks and discontinuities in the contact stress.

To overcome these deficiencies, both the ceramic layer and penetrator were converted to Smooth Particle Hydrodynamic (SPH) representation. SPH is limited to isotropic materials, so the model, shown in Figure 4, became a mixture of Lagrangian and SPH. Using this formulation, the crack pattern and extension of cracks in the ceramic compared well with test data shown in Figure 5.

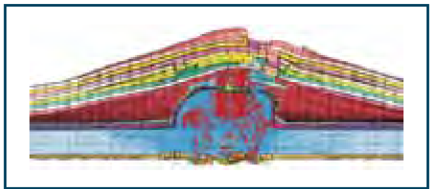

Figure 4 Mixed Lagrangian and SPH Simulation of the Bullet Impacting the Floor Section

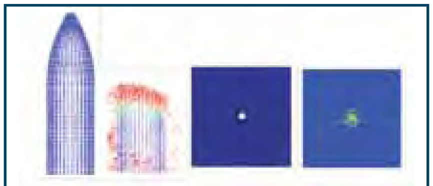

Figure 5 Predictions of Damage to Penetrator, CMC Layer, and Ceramic Layer

The modeling of composite materials such as Dyneema® was challenging during this project and still remains so. The Dyneema® model used brick element layers and a composite damage material model. The failure parameters were calibrated to accurately predict penetration over a limited range of conditions.

Virtual Floor Design

Eight IAF panels were designed to replace the three unarmored panels currently installed in the UH-60M, depicted in Figure 6. The IAF panels were reduced in size to meet the two-man-lift weight limit of 88 lbs recommended by MIL-STD-1472. The floor panel joints were aligned transversely at existing frame locations to avoid splitting tie-down fitting pans centered on the four longitudinal beams. One exception was the joint between the aft two panels, where an extra support member was added to avoid splitting three unique seat tie-down pans located above an existing frame.

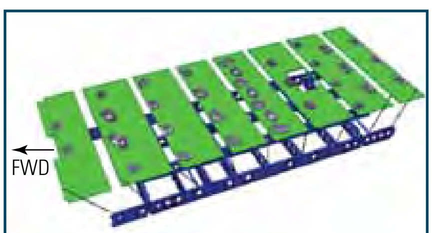

Figure 6 Virtual Floor Design

The virtual design also detailed the layered construction and installation of the IAF, shown in Figure 7. At each bolt location, a nylon bushing was added to the hard Ceramic/CMC layer to prevent wear under vibratory loads, and Epocast® densification was incorporated to prevent core crush in the top layer. Additionally, compression-resistant spacers were added to the Dyneema® layer at each fastener location to prevent creep and loss of fastener preload. The top layer was designed to incorporate the same skins and core that are used on the current floor. To accommodate the Dyneema® layer, the core was made thinner than the current floor.

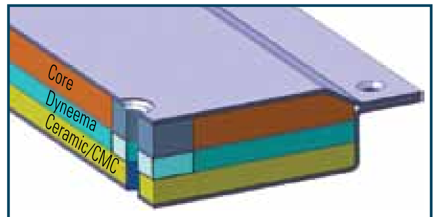

Figure 7 Typical IAF Section Cut

Validation Testing

The IAF test panel configuration, in Figure 8, was very similar to the full scale Virtual Floor design. The test panel included the same stack of lower skin, Ceramic/CMC, Dyneema®, and a top sandwich panel. However, to reduce fabrication cost, the test panels omitted the flanged close-outs, core densification at fastener locations, and cargo tie-down provisions that were not needed for ballistic and cargo impact testing. While the bare armored floor test specimen was somewhat lighter, the Virtual Floor design included tie-down rings and seat pans, and weighed approximately 8.6 pounds per square foot (lb/ft^2).

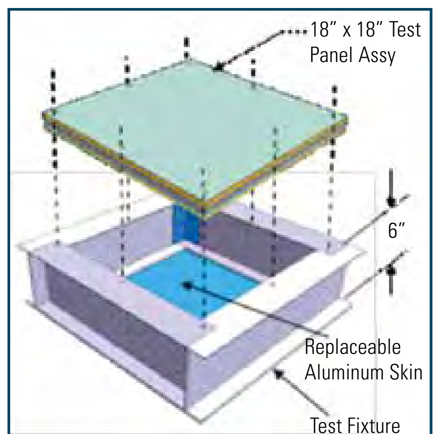

Figure 8 IAF Test Panel Configuration

The test fixture was made from 6-inch high aluminum I-beams with a 0.032-inch thick aluminum skin to represent the lower fuselage structure of the H-60 helicopter. The lower skin and top test panel could be easily removed and replaced to permit multiple ballistic tests using the same fixture. Two 18-inch by 18-inch sub-elements were required for ballistic testing.

In all, five 18-inch by 18-inch Ceramic/CMC panels were fabricated. Only three were required for testing, but it was expected that it would take multiple tries to produce a quality tile. Any additional tiles would allow for more ballistic testing. As manufactured, all five tiles were uniform in weight and thickness, and when inspected by X-ray, found to be crack free, though one tile fractured during the hole drilling process for attachment screws.

Static Strength Testing

The static load requirement for the floor was 300 lb/ft^2 cargo weight, times a 3.5 inertial maneuver load factor, times a 1.5 safety factor. This resulted in an 11 pounds per square inch (psi) load on the floor. Both floor sub-elements were tested, with a distributed static load of 3,575 lbs, equivalent to just over 11-psi, shown in Figure 9. No snapping or cracking noises were heard during the application of the load and none of the floor layers appeared to be damaged by the test.

Figure 9 Sub-Element in Load Frame

Box Drop Testing

To perform the box drop test, a 200 lbs box was raised 15 inches above the floor and dropped onto the floor center so that one rounded corner of the box impacted the floor. The floor was supported on two edges by rails and loosely clamped to the rails to prevent it from shifting during the impact, shown in Figure 10.

When the box impacted the floor, the floor did not collapse, and the box rebounded from the surface. To pass the box drop test, the permanent local deformation in the floor must not exceed 0.3 inches. After the test, there was almost no dent in the top surface. The core material was crushed directly under the impact, but the skin of the core snapped back almost flush. The skin of the core did not rupture, and there was no deformation of the Ceramic/CMC layer. Damage to this layer was not detectable visually or by tapping the panel. The box drop test was therefore deemed a success. X-ray examination of the Ceramic/CMC layer did reveal a crack pattern, shown in Figure 11. The cracks were very faint and thin, which may mean that they did not penetrate the entire thickness.

Figure 10 Box Drop Test Setup

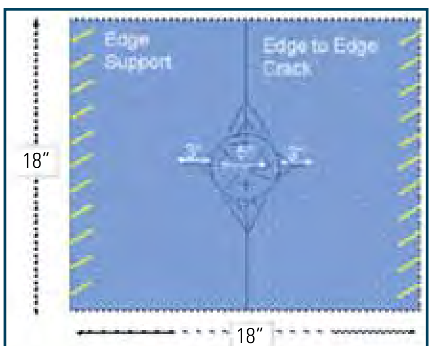

Figure 11 Ceramic/CMC Crack Pattern Post Box Drop

Ballistic Testing

The Aviation Applied Technology Directorate (AATD) at Ft. Eustis conducted the ballistic testing of two floor sub-elements. [4] One floor sub-element was mounted vertically in a test fixture and shot once, at just above service velocity. The bullet impacted the center of the floor section, which successfully defeated the round. Examination of the top (walking surface) of the floor showed a smooth bulge (less than 0.25 inches high) over an area of 5 inches diameter. No material broke free from the top of the floor. The bullet was recovered from the cavity between the thin aluminum panel representing the helicopter outer skin and the bottom (lower surface) of the floor.

The second floor sub-element was shot twice, at just above service velocity. The impacts were on 4-inch centers. Both rounds were defeated. No material broke free from the top of the floor, and there was an 8-inch by 4-inch area that bulged slightly (less than 0.25 inches) on that surface. The bullets were found in the cavity between the bottom of the floor and the thin panel representing the skin of the aircraft.

AATD also conducted the post box drop floor section ballistic test to evaluate the ballistic capability of the panel after it had sustained damage due to wear and tear. [5] The box drop test showed that the hard layer in the floor could be damaged without visual evidence. The first shot was directly on a known crack, the second shot was at the tip of a crack, and the third shot was slightly removed from a crack. All three shots were at or slightly above service velocity. All of the rounds were successfully stopped, and no material broke free from the floor.

Post Ballistic Impact Static Strength Testing

The floor sub-element shot once was subsequently subjected to the static load test. No snapping or cracking noises were heard during the application of the load and none of the layers of the floor appeared to be damaged by the test. The floor was able to support the entire load required of the undamaged floor.

Weight Analysis

The weight of the IAF design was compared to the baseline floor/armor system using parasitic steel armor, shown in Table 1. The weight savings of the IAF design, as installed, was 44% (or 496 lbs) when compared to the baseline, exceeding the goal of 33%. The total installed weight of the IAF included all of the cargo and seat tie-down provisions. The hard armor layer makes up the majority of the weight of the IAF.

Table 1 Weight Comparison Chart

	Baseline Floor/Armor System	Installed Armored Floor
Areal Weight	15.18 lb/ft^2	8.57 lb/ft^2
x 75 ft^2 (Floor Area)	1138.5 lbs	643 lbs
Normalized Weight	1.00	0.56

Cost Analysis

A manufacturing cost analysis comparing the IAF and the baseline floor/armor system showed that the IAF was estimated to cost 18% more. However, the IAF design approach has the added benefit of reduced floor thickness and lower installation costs compared to any competing bolt-on ceramic armor kit.

Conclusions

The integrally armored floor met or exceeded all weight, ballistic, cost, strength, and durability goals of this project. The weight goal of the program was a savings of at least 33%. The IAF design, however, is 44% lighter than the baseline floor/armor system using parasitic steel armor. The IAF passed all ballistic tests against the specified 7.62 x 39 mm API round at service velocity. The IAF was able to defeat two rounds on 4-inch centers, and was able to carry the full static load required before and after being shot one time. The IAF passed the 200 lb box drop test and then defeated three rounds in or near the box drop damaged area. The Virtual Prototype design showed how the IAF could be integrated into the UH-60M helicopter. In addition, cost estimates showed that the IAF can be affordable compared to current floor/armor systems using parasitic steel armor, and the additional cost is very reasonable given the weight savings.

Recommendations for Future Work

The project results indicate opportunities for future, related efforts. First, further maturation and qualification efforts would serve to prepare the IAF for incorporation into US military aircraft. Second, a follow-on project to revisit the floor design for the reduced threat of the 7.62 x 39 mm ball round would leverage much of the effort of the present project, while providing a lighter weight integral protection system option to the military.

Acknowledgements

This project was partially funded by the AATD under Agreement Number (No.) W911W6-06-2-0001 and by the Joint Aircraft Survivability Program Office (JASPO) as Project No. V-06-01.

References

1. Gooch, G.A., & Burkins, M.S. (2004). Analysis of Threat Projectiles for Protection of Light Tactical Vehicles, Army Research Laboratory, Report No. ALR-RP-89.
2. Cronin, D.S., Bui, K., Kaufmann, C., Mcintosh, G., & Berstad, T. (2003). Implementation and Validation of the Johnson-Holmquist Ceramic Material Model in LS-Dyna. Proceedings, 4th European LS_DYNA Users Conference.
3. Johnson, G.R. & Holmquist, T.J. (1998). Test Data and Computational Strength and Fracture Model Constants for 23 Materials Subjected to Large Strain, High Strain Rates and High Temperatures, Los Alamos National Laboratory, Report No. LA-11463-MS.
4. Robeson, M. (2007). Integrally Armored Floor (IAF) Ballistic Validation Testing, AATD Technical Report TR 08-D-02, DTIC AD No. ADB333063.
5. Robeson, M. (2007). Integrally Armored Floor (IAF) Phase II Ballistic Validation Testing, AATD Technical Report TR 08-D-20, DTIC AD No. ADB336800.

Helicopter Hostile Fire Indicator Test Facility

by Joseph Manchor

Helicopters are particularly susceptible to threat impact from small arms and unguided munitions due to their inherent low-and-slow flight parameters. It is often not obvious to aircrew when they are under fire. A large amount of projectiles may be expended, with the attack occurring over a considerable period of time until the craft may actually be impacted by the enemy. It would be of immense value if the pilots of these craft could be quickly alerted to incoming fire so that they may take evasive maneuvers.

Hostile Fire Indicator (HFI) systems have been proposed as potential solutions to this problem. Varied levels of testing are required to assist in bringing these systems to fruition. The Weapons Survivability Laboratory (WSL) at Naval Air Warfare Center Weapons Division (NAWCWD) China Lake, CA, has been proposed as one of several sites for this testing. This is due to the unique capabilities that may be provided by this facility.

A helicopter may pose unknown influence to candidate HFI systems through the inherent extremes of its operating environment, such as noise and vibration. The close proximity of high-speed rotating components may pose additional influence to these systems. Testing of HFI systems within an actual operating helicopter provides a significant challenge due to obvious safety concerns of firing threat projectiles near a manned helicopter. With this in mind, a capability has been developed that provides testing of these systems while installed within a *remotely operated* helicopter. This capability is provided at the WSL Remote Test Site (RTS) HFI facility.

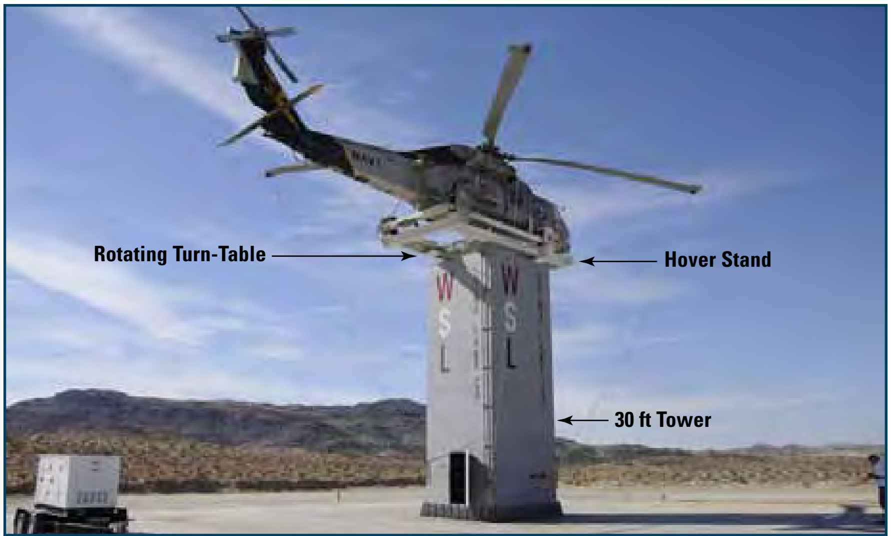

Figure 1 HFI Test Pad's Helicopter Tower

At this facility, candidate HFI sensor systems may be installed within an operational helicopter. The helicopter is elevated on a tower approximately 30 feet higher than ground level to accommodate a variety of shot lines and to minimize potential ground interference to the sensor system (see Figure 1). For testing, the helicopter is brought to remote controlled hover flight on top of the tower, and the helicopter's installed HFI systems are activated. Weapon systems are then aimed and fired for varied near misses at the helicopter. The HFI systems then may collect and record their data. In this manner, threat signature data may be collected for the development of new or existing HFI systems, along with providing data for the continued development of HFI algorithms.

Remote Controlled Helicopter

The helicopter is secured to the tower *via* a hover stand equipped with rubber airbag actuators. The hover stand and its actuators allow the aircraft to safely achieve 1G hover conditions. The stand both restricts the aircraft from departing the tower while allowing some movement and vibration similar to that of actual hovered flight. The stand also minimizes the potential for the aircraft to encounter hazardous ground resonance conditions.

The hover stand and helicopter are affixed to a powered rotating table placed atop the tower to allow easy reorientation of the helicopter's azimuth during or between test events.

The helicopter is instrumented for remote engine and flight control. Cockpit warning and caution lights are monitored remotely through the use of cockpit mounted video cameras. Engine power levers movement is controlled through the use of remote actuators. Collective and yaw controls are also controlled through the use of remote actuators. Cyclic (roll and pitch) control is fixed and held in the neutral center position, as determined and adjusted during pre-test run-ups of the aircraft on the hover test stand. Figure 2 and Figure 3 illustrate these controls.

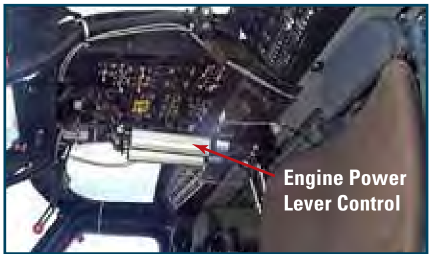

Figure 2 Engine Power Lever Control

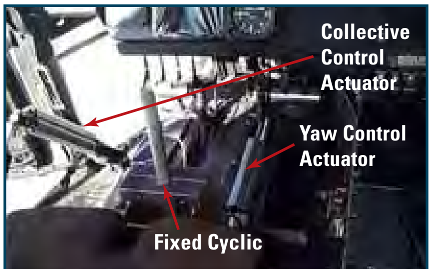

Figure 3 Collective, Cyclic and Yaw Control

Test Assets

Multiple test aircraft are available for this testing and include SH-60B and UH-1H aircraft (see Figure 4 and Figure 5). These aircraft have all been stricken from the active service inventory, but are still capable of flight. The aircraft have all necessary operating components for flight: engines, gearboxes, flight control system, hydraulic system, electrical system, and internal fuel cells. The aircraft have been modified to provide installation space and power for the HFI systems and any other internal aircraft support systems for testing.

Figure 4 SH-60B Helicopter 161566

Figure 5 UH-1H Helicopters 70-16350, and 73-22082

Firing Range

Flexible firing positions are available to provide varied firing distances for the threat weapon systems (see Figure 6). The main firing positions are located at 1 Km, 2 Km, and 3 Km from the test pad where the helicopter is hovered. In addition, a near shot firing road connects the 1 Km Gun Site with the RTS HFI Test Pad. Both this road and the main access road leading to the RTS pad are utilized for close-in firings of up to 1 Km from the RTS Test Pad. Figure 7 illustrates an example gun view from the Main Access Road. For all of these firings, the weapons are aimed to provide shotlines for varied miss distances from the helicopter. None of the weapons are aimed to actually impact the helicopter.

Figure 6 RTS HFI Test Facility Firing Positions

Figure 7 Example Gun View from Main Access Firing Road

Fiber Optic Network

Fiber optic cable is installed from the RTS helicopter hover test pad to each of the gun sites. Patch nodes are available at the 1 Km, 2 Km, and 3 Km Gun Sites. Patching nodes are also installed at 250m intervals along the near shot firing road (see Figure 8). The nodes are available to patch test pad helicopter, fire fighting, and video control and monitoring signals. The test pad and 3 Km patch nodes have the additional requirement to relay and monitor control and data signals from the HFI system. In addition, a portable rollout fiber optic extension cable is utilized for patching to the network up to 1,000m from any of the nodes. This cable is primarily intended for remote patching to the network at intermediate points along the near shot firing road and along the main access road leading to the test pad.

Portable Fire Control Center (The War Wagon)

A portable trailer has been constructed to concurrently serve as both a control center and gun firing platform (see Figure 9 and Figure 10). The trailer includes the capability to patch to the fiber optic network at each of the planned firing sites. A portable generator is transported with the trailer to provide AC power to the Control Center.

The Control Center serves to control the remote operation of the helicopter, and also includes limited data recording capability. Firing input to the gun is

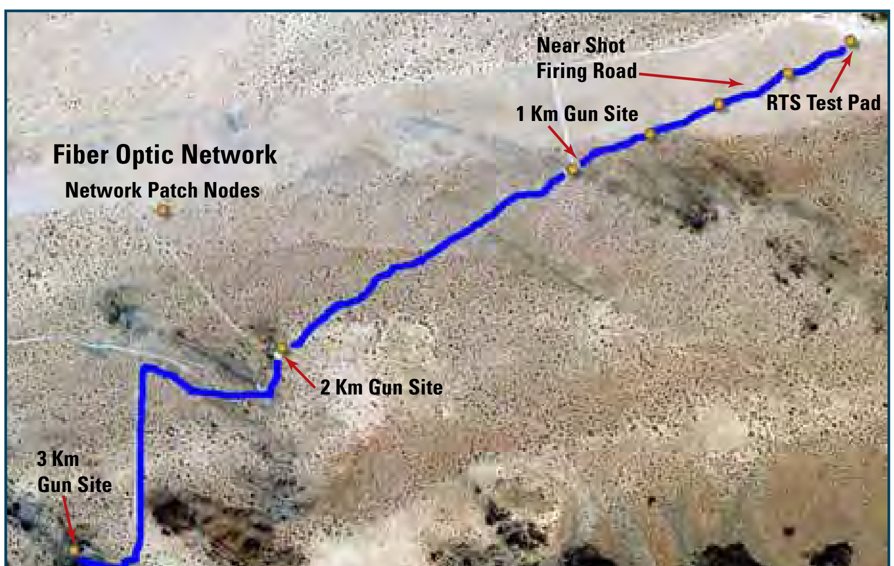

Figure 8 Fiber Optic Network

Figure 9 Portable Fire Control Center (The War Wagon)

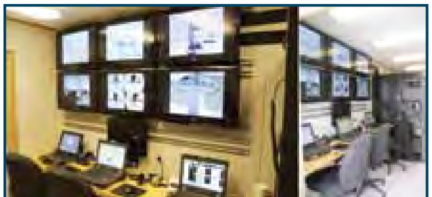

Figure 10 Portable Fire Control Center Interior

also controlled from within the trailer. The primary signals monitored at the Control Center include all helicopter operating parameters, along with video feed of the test pad. Control signals sent from the trailer to the test pad are all helicopter operations control signals, video pan/tilt zoom control, along with remote firefighting equipment control signals.

Command Center

A Command Center is located at the 3Km Gun Site firing position. The center serves as the primary planning, control, and data collection center for the visiting engineers and technicians of the tested HFI systems. A large array of video screens provides a visual overview of the test progress. Numerous fiber optics patches are available within the command center to provide control and data collection relay to/from the installed HFI systems within the helicopter.

Weapons Systems

An assortment of weapons fire similar to the ones used in the areas of conflict can be directed to pass near the helicopter. The site provides for firings of threat weapons from 5.45mm small arms to 40mm anti-aircraft gun systems at specified shotlines, bursts, and projectile mix of ball, armor piercing, armor piercing incendiary, high-explosive incendiary, and tracer (Figure 12). Rocket propelled grenades (RPG) and other unguided rockets are also currently approved for test firings at this range with inert warheads (Figure 13). Higher level threats (such as Man Portable Air Defense Systems) are planned for the future.

Future Capabilities

Range improvements are planned to provide enhanced test capabilities to satisfy customer requirements. Near-term planned improvements include an additional tower with a remote controlled helicopter to be constructed on a nearby hilltop to provide the added flexibility of weapon shotline selections. Other hills adjacent to the test facility also provide the opportunity for downward shotlines to simulate mountainous threat encounters in Afghanistan. Other capabilities will be considered as per customer needs.

The NAVAIR Combat Survivability Division oversees management and scheduling of this facility. ■

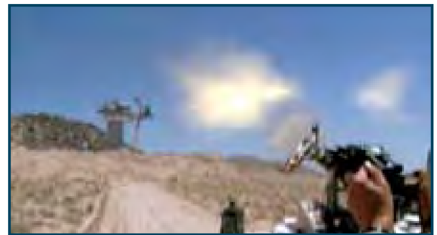

Figure 12 .50 Cal. HFI Test

Figure 13 RPG HFI Test

Figure 11 Command Center

Excellence in Survivability – John J. Murphy, Jr.

by Ralph Speelman

The Joint Aircraft Survivability Program (JASP) is pleased to recognize Mr. John J. Murphy, Jr., for Excellence in Survivability. John is Technical Director for the Air Armament Center, 46th Test Wing, 46th Test Group, Aerospace Survivability and Safety Operating Location at Wright-Patterson Air Force Base, Dayton, OH. For 25 years, John has been a leader in advancing and applying technology to predict, evaluate, and improve combat survivability of US flight vehicles. John graduated from the University of Cincinnati in 1986 with a BS degree in Mechanical Engineering. He followed that with a 1991 MS degree in Mechanical Engineering from the University of Dayton.

John has served as technical specialist, program manager, mentor, supervisor, Air Force Technical Advisor for Live-Fire Test and Evaluation (T&E) (LFT&E), Air Force Deputy Test Director for Joint Live Fire, and Office of the Secretary of Defense (OSD) Joint Test Director for Joint Live Fire. John's efforts in developing technology for understanding and improving live-fire combat tolerance have directly benefitted US flight vehicles including: C-130, C-17, C-5, KC-X, JCA, F-15, F-16, F-22, F-35, F-117, B-1, B-2, Predator UAV, Airborne Laser, and various Army and Navy systems. John has been author, co-author, or technical advisor for over 100 reports. His achievements have been recognized with nearly 40 awards for engineering and managerial excellence.

For the first 10 years of his career, John focused on technologies for understanding and reducing risks to warfighting aviators caused by aircraft vulnerability to combat damage. These risks included wing dry bay fires and explosions, hydrodynamic ram damage to fuel system structures, fuel system fires and explosions, and engine nacelle fires and explosions. While John structured his projects to understand and improve combat survivability for a customer's specific aircraft, he insured that results were captured and documented in a manner to create value for both legacy and emerging flight vehicles. The survivability of our warfighters using the C-130 and C-17 is a direct result of his attention to lessons learned during the early portion of his career. It was during this period that John became known for his ingenuity in development of test articles that were both high-fidelity and easily-repairable, advancement of live-fire test facilities to support the emerging sciences for vulnerability reduction, advancement of instrumentation for understanding events that occur in the blink of an eye, and increased use of labor-saving computer-aided tools for T&E data management and analysis. The greatest foundation of John's technical reputation was his insistence on use of what eventually become known as the model-test-model approach for planning and executing LFT&E.

Some specific accomplishments include—

- Upgrading of the Air Force Vulnerability Assessment test facility to accommodate full-scale test article exposure to operationally representative conditions including airflow, g-loading, and flammable fluid thermal conditioning
- Planning and directing LFT&E to quantify C-130 and C-17 combat damage vulnerability and documenting this in a format which became the Air Force template for systems subject to vulnerability LFT&E Congressional Oversight
- Developing the concept of using high-fidelity and easily-repairable test articles for in-depth exploration of technical issues
- Creating the benchmark process of using operational battle damage repair specialists to expedite test asset repair while they acquired firsthand experience in quickly repairing fight system damage representative of combat
- Understanding the sequence of events leading to, and providing a high-tech T&E capability for evaluating design alternatives to reduce, catastrophic consequences of hydrodynamic ram, dry bay fire, and fuel system fire.

The second decade of John's focus on the needs of the warfighter evolved into more of a leadership, supervisory, and technical consulting role. During this period, he led an eight person staff to assist OSD and aircraft program offices in planning and executing LFT&E. He also led a 50+ person contract team in providing support for LFT&E execution and for understanding and resolving issues critical to vulnerability prediction, assessment, and reduction. For over half of this decade he served as an OSD technical advisor on tri-service initiatives addressing cross-service common issues for reducing vulnerability of both legacy and developmental aircraft. His insistence on cross-service collaboration resulted in the significant increase in tri-service corporate knowledge now being applied in understanding, evaluating, and improving combat survivability.

His accomplishments include—

- Establishing collaborative arrangements with aircraft program offices to assist their understanding of LFT&E complexity and with Department of Defense (DoD) LFT&E specialists to assist in evaluating design alternatives prior to actual system exposure to high-visibility LFT&E
- Understanding and reducing risks to US aircraft created by operational exposure to Rocket-Propelled-Grenades and Man-Portable Air Defense System missiles
- Adaptation of manned flight vehicle vulnerability assessment and reduction technologies to understand and increase the combat survivability of unmanned systems
- Using archive data from the early days of Air Force, Army, and Navy LFT&E to provide answers needed in assuring continued survivability and safety of legacy aircraft being operated outside their originally intended LFT&E exposure conditions and beyond their originally planned lifetimes
- Understanding foreign system survivability strengths and weaknesses through live-fire testing to evaluate weapon system effectiveness.

The most recent years of John's service have involved additional increases in responsibility to include service as Chief Engineer and now as Technical Director for a 20+ person organization with a 100+ person contract support staff.

This team is dedicated to accelerating the process of predicting, understanding, and reducing negative consequences of mission related damage to Air Force flight systems. Part of this initiative is pushing the discovery and correction of vulnerability deficiencies further back in the system development cycle where they are less costly to fix.

John served as Air Force lead technical specialist in developing the transition plan for implementing a Base Realignment and Closure (BRAC) requirement to reduce DoD costs by conducting Air Force LFT&E operations at the Navy LFT&E facility. John was instrumental in achieving the BRAC objective, while preserving the Air Force's ability to meet its internal responsibilities to evaluate vulnerability reduction design alternatives during flight system development, understand and resolve operational problems, and extend technologies which can reduce the need for, or costs of, LFT&E.

Accomplishments under his leadership include—

- Use of Air Force LFT&E expertise to organize and lead a tri-service collaborative effort which completed the Joint Cargo Aircraft $15M LFT&E program in three years instead of five years as initially planned; awarded an Exemplary Civilian Service Award as a result
- Development and application of field-portable techniques for assessment of heat-seeking missile probable miss distance during T&E being conducted to evaluate missile improvements and flight vehicle missile countermeasures
- Development and application of an ability to launch heat-seeking missiles under LFT&E facility controlled test conditions necessary for high-tech-instrumented vulnerability assessments
- Exploration and advocacy for adapting aircraft vulnerability assessment and reduction technologies for use by the spacecraft community in protecting against damage caused by orbital debris
- Adaptation of military system vulnerability assessment and reduction technologies for use by the commercial aircraft community in understanding and reducing operational risks of hostile actions involving shoulder-launched heat-seeking missiles.

Mr. Murphy has been a vital member of any team he has had the privilege to work with or lead. He has established a reputation for being able to balance warfighter needs, Congressional Oversight, and realities of budgets and schedules. It is a reputation so well respected, that he is sometimes requested to provide supporting rationale for both sides of an underlying technical argument. The combat hardness of today's fighting vehicles, across all services, speaks in obvious tribute to his dedication and pursuit of excellence in achieving survivability and safety for our warfighting aviators.

His family consists of: wife Karen, and children: Kaitlyn (22), Allison (19), and Joseph (15). John's hobbies include reading, golfing, and active involvement in whatever activities are of interest to his family. He has especially enjoyed the opportunities to assist at sports events and other school functions.

It is with great pride and pleasure that the JASP honors Mr. John Murphy, Jr., for his Excellence in Survivability contributions to the technical community, the JASPO, the survivability discipline, and the warfighter. ■

2010 NDIA CSD Aircraft Survivability Awards and Presentations

by Dennis Lindell

The National Defense Industrial Association (NDIA) Combat Survivability Division (CSD) held its annual Aircraft Survivability Symposium at the Naval Postgraduate School (NPS) on 2–5 November 2010. The Aircraft Survivability 2010 theme was, "Today's Successes, Tomorrow's Challenges." The symposium focused on identifying and applying the survivability lessons from current combat aircraft to address the new threats and requirements that challenge the survivability programs of tomorrow's aircraft. The Keynote Speakers were Mr. Alan Wiechman, Vice President, Special Technology Integration, Phantom Works, Boeing Defense & Space Security; and Dr. Catherine Warner, Science Advisor to the Director, Operational Test and Evaluation, Office of the Secretary of Defense.

NDIA CSD Awards

The NDIA CSD Awards are presented annually at the Aircraft Survivability Symposium. These awards recognize individuals or teams demonstrating superior performance across the entire spectrum of survivability, including susceptibility reduction, vulnerability reduction, and related modeling and simulation.

The Admiral Robert H. Gormley Leadership Award, named in honor of the CSD's founder and Chairman Emeritus, was presented to CAPT Paul J. Overstreet, USN, Program Manager for Advanced Tactical Aircraft Protection Systems, PMA-272 at Patuxent River Naval Air Station, MD. The NDIA Combat Survivability Award for Technical Achievement was presented to Mr. Michael Pochettino, Senior Consulting Engineer, Northrop Grumman. The presentations were made by Mr. Robert Palazzo, CSD Awards Committee Chairman; Mr. Ronald Ketcham, 2010 Symposium Chairman; BG Stephen D. Mundt, USA (Ret), CSD Chairman; and RADM Robert H. Gormley, USN (Ret), CSD Chairman Emeritus.

Admiral Robert H. Gormley Leadership Award

The Admiral Robert H. Gormley Leadership Award is presented annually to a person who has made major leadership contributions to combat survivability. The individual selected must have demonstrated outstanding leadership in enhancing the overall discipline of combat survivability, or played a significant role in a major aspect of survivability design, program management, research and development, modeling and simulation, test and evaluation, education, or the development of standards. The emphasis of the award is on demonstrated superior leadership over an extended period. The 2010 Admiral Robert H. Gormley Leadership Award was presented to CAPT Paul J. Overstreet, USN. The citation read,

"Captain Paul J. Overstreet, USN is the Program Manager for Advanced Tactical Aircraft Protection Systems, PMA-272 at Patuxent River Naval Air Station, MD. Aircraft Survivability Equipment has taken on an increasingly important role as a result of a marked increase in aircraft losses and personnel fatalities during Operations in Iraq and Afghanistan. Captain

Admiral Robert H. Gormley Leadership Award
From left to right – RADM Robert H. Gormley, USN (Ret), CSD Chairman Emeritus; CAPT and Mrs. Paul Overstreet, USN, Admiral Robert H. Gormley Leadership Award recipient; BG Stephen D. Mundt, USA (Ret), CSD Chairman

Overstreet's team at PMA-272 has addressed this situation by enhancing the warfighter capability and survivability of Navy and Marine aircraft. Among the many actions taken under his leadership, the PMA-272 team has rapidly equipped Marine Corps helicopter platforms deployed to Iraq and Afghanistan with AAR-47 and ALE-47 Forward Firing Dispensers and is credited with saving a V-22 that was engaged by Man-portable air-defense systems; directed the installation of the AN/AAQ-24 Infrared Countermeasures System on the CH-53D/E, and CH-46E helicopters; and initiated the JATAS System for an advanced IR Missile Warning System for Navy and Marine platforms.

Prior to his assignment to PMA-272, Captain Overstreet was associated with Aircraft Survivability in the area of support jamming holding squadron leader positions during deployments with the EA-6B to the Persian Gulf and Indian Ocean and in 2003 was selected as the Chief Engineer on the Navy's newest support jamming platform the EA-18 Growler.

Through his superior accomplishments, Captain Paul Overstreet is awarded the RADM Robert H. Gormley Combat Survivability Award for Leadership in 2010."

Combat Survivability Award for Technical Achievement

The NDIA Combat Survivability Award for Technical Achievement is presented annually to a person or team who has made a significant technical contribution to any aspect of survivability. It may be presented for a specific achievement or for exceptional technical performance over a prolonged period. Individuals at any level of experience are eligible for this award. The 2010 Technical Achievement Award was presented to Mr. Michael Pochettino, Senior Consulting Engineer, Northrop Grumman. The citation read,

"The technical innovation and leadership of Mr. Michael Pochettino has been key to the success of the development of airborne radar programs, most significantly, the Joint Strike Fighter F- 35 radar – APG-81. Survivability is critical to the success of the F-35 mission, and the Active Electronically Scanned Array is the critical state-of-the-art technology component of the F-35 weapon system. Traditionally, an AESA could be a detriment to the survivability of an aircraft – and system trades and compromises are reached on radar performance versus aircraft survivability. Mr. Pochettino's leadership and innovation has optimized the integration of performance and survivability – and instead of compromise – the APG-81 is the world's most advanced AESA, optimizing performance in a challenging EW environment. At the forefront of the JSF Program is the APG-81 and its' recognized world class Electronic Protection.

Mr. Pochettino has spent over 25 years at Westinghouse, now Northrop Grumman, developing and working on numerous radar programs to include the APG-66 and 68 for the F-16, the APG-77 for the F-22 and now the APG-81 for the F-35.

Mr. Michael Pochettino is well-deserving of the award for Technical Achievement for Combat Survivability in 2010."

Combat Survivability Award for Technical Achievement
From left to right – Mr. Robert Palazzo, CSD Awards Committee Chairman; Mr. Michael Pochettino, Technical Achievement Award Recipient; BG Stephen D. Mundt, USA (Ret), CSD Chairman

Poster Paper Awards

Awards were also presented for the symposium's top three poster papers. First place went to Ms. Kathy Russell of Naval Air Systems Command and Mr. Nick Gerstner of SURVICE Engineering Company for their paper, "CH-53K Heavy Lift Helicopter – A Survivability Focused Design." Second place went to Mr. Darrell Liardon of Bell Helicopter Textron for his paper, "Self-Healing Coatings for Vulnerability Reduction." Third place went to Mr. Troy Miklos of Lockheed Martin Corporation for his paper, "Relating RF and LWIR Detection Ranges for Aircraft Susceptibility."

Best Poster Paper Awards
From left to right – Mr. Darrell Liardon (2nd Place), Mrs. Kathy Russell and Mr. Nick Gerstner (1st Place), and Mr. Troy Miklos (3rd Place)

Aircraft Survivability 2011

Preparations are underway for Aircraft Survivability 2011, "Survivability in a Complex Threat Environment." Scheduled for 1-3 November 2011, this important event will focus on aircraft design and enhancement of susceptibility, vulnerability, and tactics for surviving the currently emerging and next generation of complex and lethal threats. Details regarding the 2011 Symposium Call for Abstracts, Displays and Award Nominations will be available on the event website: *http://www.ndia.org/meetings/2940*. ■

If you're in the Survivability Business, Monterey is the Place to be in November!

Aircrew and Aircraft Occupant Vulnerability Demonstration

by Gregory Fuchs, B. Joseph McEntire, Patricia Frounfelker, and Marsha Fridie

The Joint Aircraft Survivability Program (JASP)-sponsored Threat Weapons and Effects Seminar (TWES) is hosted by the Joint Combat Assessment Team (JCAT) every April. This seminar draws information from threat exploitation, live fire testing, and combat experience to provide a complete picture on threat lethality. Whereas the seminar's primary objective is to train JCAT personnel and facilitate the dissemination of survivability data, in 2010, the team collaborated with the US Army Aeromedical Research Laboratory (USAARL) and the US Army Research Laboratory, Survivability/ Lethality and Analysis Directorate (ARL/SLAD) to demonstrate the effects of a rocket propelled grenade (RPG)-type system against helicopter occupants.

Introduction

Recent initiatives within JASP to evaluate aircrew casualties are a result of guidance from the Director of Live Fire Test and Evaluation (LFT&E) to develop and expand tools that predict the probability and number of casualties due to weapons effects. JCAT saw the opportunity to use the TWES to further both the team's understanding of casualty-producing warhead effects and providing USAARL and ARL/SLAD with a venue to develop and refine their evaluation processes. This effort provides a more efficient use of range assets, provides opportunity to researchers to investigate emerging instrumentation and data collection concepts, and enhances the collaborative relationship between members of the survivability community who seldom have the opportunity to work together.

Methods

Aircraft

A Utility Helicopter (UH) Huey (-1H) (see Figure 1) was used as the target aircraft. In preparation for the demonstration, the aircraft engine, transmission, and many of the cockpit instruments and avionics were removed, and the fuel tank was rinsed and then filled with water, immediately prior to the demonstration. The target location of the RPG-type weapon was the left side fuselage frame, between the co-pilot door and the crew cabin large sliding door.

The crew seating arrangement was modified to more realistically mimic the seating layout of a UH Blackhawk (-60) helicopter. All seats were those traditionally used in a Huey helicopter. A total of 12 seats, four crew seats and eight passenger seats, were installed. The two pilot seats were armored pilot seats with lap belts, shoulder harnesses, and MA-16 inertia reels. Two outward facing seats of tube frame and fabric construction were installed immediately aft of the pilot seats to mimic the UH-60 crew chief/gunner seating orientation, but were configured with lap belt restraints only. These two seat positions were identified as the crew chief and gunner positions for this demonstration.

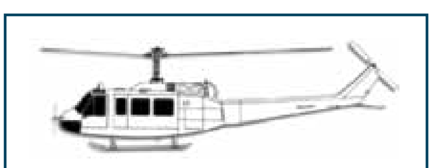

Figure 1 Towed Airborne Plume Simulator (TAPS) prior to deployment

All eight passenger seats were of tube and fabric construction and configured with lap belt restraints, typical of the Huey helicopter configuration. Four of the passenger seats were forward facing, located near the mid-fuselage position. The remaining four seats were outward facing, two facing left and two facing right, located in the aft-most location of the fuselage at the UH-1's traditional door gunner positions.

Aircrew Survivability

In an attempt to assess the fragment impact to any crew aboard the target aircraft, plywood human surrogates (see Figure 2), were placed in a seated posture in all 12 occupant locations. These are 3-dimensional surrogates typically used to capture penetrating hazards during studies of weapon lethality and crew survivability. The plywood surrogates were painted white to improve visual detection of damage from fragment impacts. Other

Figure 2 Plywood surrogates fabricated to replicate crew and passengers

instrumented surrogates were not used due to the potentially destructive effects of the primary threat.

The four plywood surrogates, which occupied the two pilot and two crew chief/gunner positions, were configured in Army Combat Uniform (ACU) (trousers and blouse), torso body armor (without ceramic inserts), survival vest (without contents), and Army HGU-56/P aircrew helmets. The intent was to appropriately mimic the gear typically worn by US Army aircrew in combat operations. However, the surrogate occupying the left crew chief position (nearest the target location) also had an experimental ballistic cover affixed to his HGU-56/P aircrew helmet. The two pilot stations are shown in Figure 3 and the left crew chief station is shown in Figure 4.

Figure 3 Pilot and co-pilot plywood surrogates

Figure 4 Left outward facing crew chief and four forward facing passengers

The plywood surrogates occupying the eight passenger seats were provided torso body armor with ceramic inserts and Advanced Combat Helmets (ACH). The four forward-facing plywood surrogates were dressed in ACUs. The next two were dressed in older one-piece style flight suits. No clothing was provided for the two plywood surrogates located in the aft-most seat positions. No footwear or gloves were provided for the 12 surrogate occupants.

Aircraft Instrumentation

The aircraft cabin was equipped with sensors in an attempt to characterize the cabin's dynamic pressure change resulting from the warhead detonation and the aircraft's structural acceleration response due to the weapon impact. Three pressure sensors were installed inside the helicopter fuselage cabin area. Two were mounted aft of the pilot and co-pilot seats on the outside wall, facing inboard approximately 8 inches below the ceiling. The third pressure sensor was located near the fuselage centerline along the rear bulkhead. This sensor was approximately 20 inches below the ceiling height and replaced a viewing port for the transmission oil level. These locations were chosen for convenience of sensor mounting and wiring routing given the limited preparation time and limited aircraft access prior to the scheduled event. The purpose for these sensors was to collect the cabin dynamic pressure changes at three distinct locations in the fuselage cabin. This data was used for comparison against the data collected with the two first generation (GEN-1) helmet sensors mounted on each of the eight passenger ACHs. Data collection from the pressure sensors was accomplished with a G5 data acquisition system manufactured by Diversified Technical Systems, Inc. The G5 data acquisition system records synchronous data from 32 sensors at a sample rate of 40,000 samples per data channel. This data acquisition system was also used to record some of the structural acceleration data signals, and for its protection, was located outside the fuselage behind a concrete "Jersey Barrier."

Two sets of tri-axial accelerometer sensors were installed in a rugged steel box and secured to the aircraft's floor. This box was mounted along the aircraft centerline between the two crew chief/gunner seats and was anchored to fuselage structural members through the pilots' lap belt anchor points. One set of the tri-axial accelerometers was laboratory grade; data from these accelerometers was collected using the G5 data acquisition system. The second set of tri-axial accelerometers was contained in the Cockpit Air Bag Systems (CABS) Electronic Crash Sensor Unit (ECSU). The ECSU is a self-contained system that senses and records the transmitted accelerations once a threshold has been exceeded. The ECSU is currently fielded on some Army aircraft which have been retrofitted with CABS and is used to sense crash accelerations and activate the CABS when a crash event is detected. The purpose for including the ECSU in this event was to determine if sufficient energy would be transmitted during an RPG-type event to activate the CABS supplemental restraint system.

The ACHs worn by the eight plywood mannequin passengers were each configured with both the internal and the external GEN-1 helmet sensors. These helmet sensors were designed to record the helmets accelerations and blast wave exposures. These sensors were added to the combat helmets in this demonstration so that the readings from both sensors could be compared to each other when exposed to the same event. This demonstration event was expected to generate a blast shock wave to the plywood surrogates and potentially produce fragmentation impacts to the helmet shells.

In an attempt to collect a visual record of the threat weapon impact, detonation, and fragmentation effects in the crew and cabin areas, two standard rate (30 images per second) video camera heads were installed near the pilot positions. One camera head was located inside the cockpit area mounted to overhead structure and viewed the passenger's cabin area. The second camera was affixed externally to the co-pilot forward windscreen, offset to capture the effects on the two pilots.

Results

Aircraft

Two of the three aircraft mounted pressure sensors captured the complete time history trace of the dynamic pressure change. The sensor located nearest the threat weapon impact location was dislocated from the aircraft structure during the weapon impact and its signal wire severed several milliseconds after impact. A time phase shift is evident in the two complete pressure sensor data traces, due to the variation in distance between the threat impact location and the placement of the three sensors.

The laboratory grade tri-axial accelerometers captured the full structural response accelerations. Since the aircraft was resting on the ground and had its mass reduced (through the removal of its engine, transmission, and much of its avionics), the rigid-body dynamic response of the aircraft body was altered from what could be expected when in flight. However, this data (see Figure 5) is useful as it

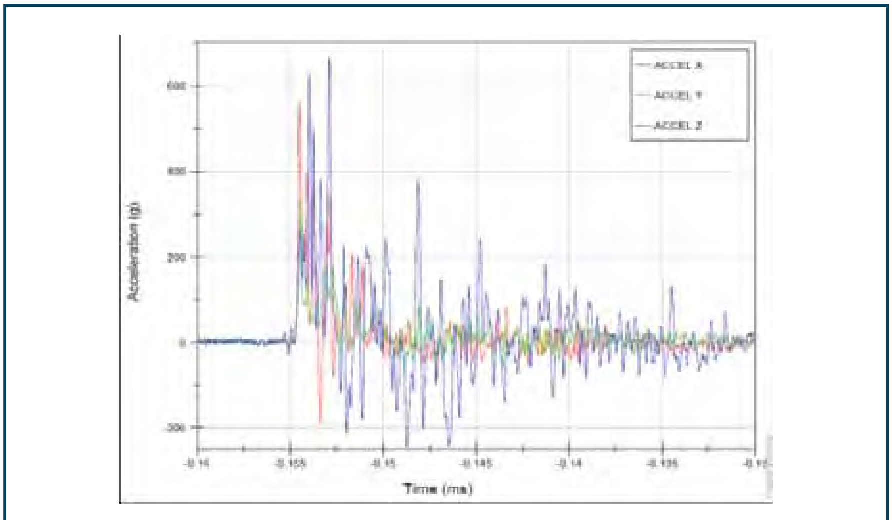

Figure 5 Left outward facing crew chief and four forward facing passengers

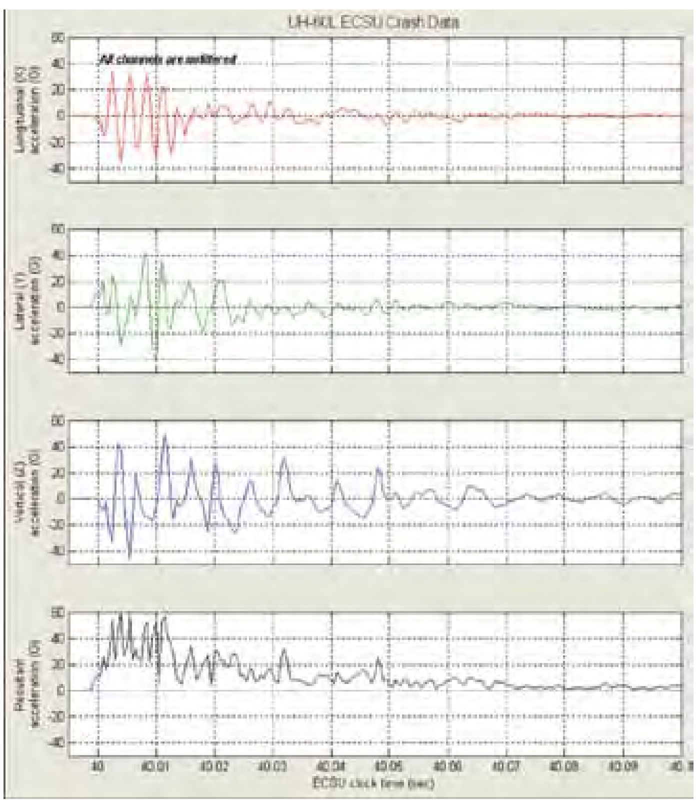

Figure 6 Unfiltered acceleration time-history traces from Electronic Crash Sensor Unit (ECSU)

provides an estimate of the structural frame acceleration magnitudes (in excess of 400G unfiltered) that could be expected in an aircraft during similar events.

The ECSU system sampled its internal accelerometers at a much slower rate (7,000 samples per second) than the G5 data acquisition system sampled the laboratory grade accelerometers (40,000 samples per second). Even so, the ECSU sensed accelerations at the 40 G (unfiltered) level for all three axes (see Figure 6), and its crash discrimination logic recognized as a significant event (*i.e.*, its acceleration thresholds were exceeded). The event did not contain enough energy to exceed the velocity change threshold and was not interpreted as a crash impact event. This means the ECSU airbag firing logic did not deploy the CABS based on the measured acceleration traces of the event. However, since the aircraft was resting on the ground and its displacement restricted by the ground contact, the risk of air bag deployment due to an RPG strike cannot be ruled out based on the ECSU data collected during this demonstration event.

The ten-fold increase in the measured structural accelerations between the G5 laboratory grade system and the production ECSU system (400 G versus 40 G unfiltered) can be attributed to the different sampling rates employed by the two data collection systems. Both tri-axial accelerometer systems were located adjacent to each other and contained in the same steel box which was rigidly attached to the aircraft's structural floor members. It is possible that structural vibrations of the steel box, along with the 4-inch displacement separation in the sensor mounting location, contributed to the acceleration magnitude variation, but it is not considered to be the primary source. Different anti-aliasing filters could contribute to some of the acceleration magnitude variation, but the different data sampling rates are considered to be the primary variation source. Application of different signal processing filters could be employed to remove structural vibrations, and the selection of the filter can dramatically alter the time-history traces of the collected signals and is not a trivial selection. Additional work is needed to select proper sensor sample rates, anti-aliasing filters, and signal processing filters for these high-onset explosive events to properly interpret these measurements.

During the event, the intensity of the pressure wave shock and fuselage acceleration response was great enough to substantially alter the lens focus setting of the internal video camera head, causing all post-impact images to be of minimal value. The power and image transmission cable to the externally mounted video head were both severed during the warhead detonation resulting in loss of all post-impact images.

A physical examination of the areas affected by the RPG-type threat impact and detonation was undertaken. The different regions affected did not have distinct boundaries between each other and therefore overlapping of characteristic damage between them is common. The immediate vicinity of the detonation was characterized by removal of subsystem components due to weakening by fragment penetrations

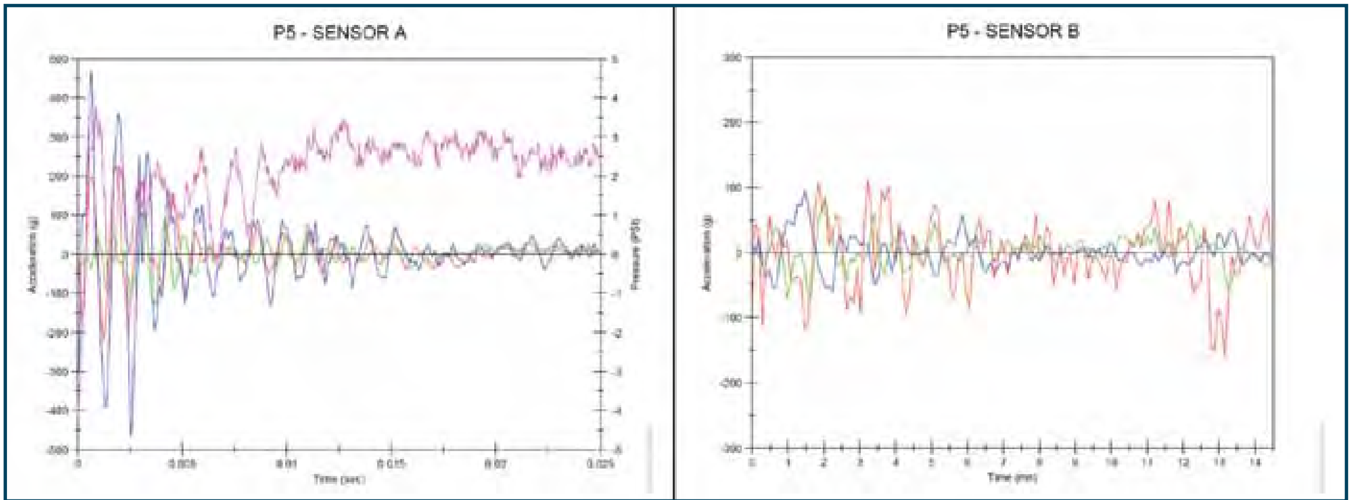

Figure 7 Helmet acceleration time-history data traces from the internal and external Helmet Sensor (HS) systems

and dislocation of pieces of the aircraft by the blast pressure wave. Other areas contained numerous high velocity fragment penetrations, soot residue from the explosive, and exhibited some distortion of the aircraft structure and components due to the blast pressure wave. Other areas of the aircraft examined contained more widely spaced high velocity fragment penetrations, with little evidence of sooting or pressure wave damage. Some areas contained only occasional high and low velocity fragment penetrations.

Aircrew Survivability

After the RPG-type threat impact and explosion, plywood surrogate damage was analyzed by visually inspecting the surfaces of each plywood surrogate and recording the location on the body and the penetration depth and size of each fragment witness mark. This fragmentation data was processed using the Operational Requirement-based Casualty Assessment model to determine the casualty effects. Preliminary results indicate that several of the plywood surrogates received direct warhead damage, others received fragmentation damage only, and several received no damage at all. Visual inspection of the passenger's torso body armor vests revealed no fragmentation witness marks, and X-ray inspection of the ceramic inserts revealed no evidence of projectile impact damage.

Helmet sensor data indicated that for each helmet, internal and external sensor readings were very different. More testing is needed to determine why the two sensor systems recorded different acceleration readings when placed on the same helmet. An example of the two helmet sensor acceleration time-history traces is shown in Figure 7. All eight of the internal helmet sensors located at the helmet crown detected an event and recorded acceleration and pressure change data while only three external helmet sensors recorded data. None of the external helmet sensors registered the event as a blast event.

Conclusions

The collaboration between the JCAT, USAARL, and ARL/SLAD is an outgrowth of a Memorandum of Agreement (MOA) between the Army Component of the JCAT and US Army Medical Research and Materiel Command. While this MOA was originally developed to assist both organizations in their primary mission, it is clear that close collaboration between the survivability and medical research communities is beneficial and supportive of efforts to ensure aviation platforms are made as safe and survivable as possible. ■

The opinions, interpretations, conclusions, and recommendations are those of the authors and are not necessarily endorsed by the US Army and/or the Department of Defense.

Today's IRCM Systems: Smarter Than Us?

by Brad Thayer

Over the last 10 years, fielded missile warning and infrared (IR) countermeasures systems (MWS and IRCM) have rapidly increased in complexity and performance. This has pushed the test community to develop ever more sophisticated test capabilities in order to fool the systems into thinking the aircraft is being fired upon by an actual live Man Portable Air Defense Systems (MANPADS) or other IR-guided missile. This is a necessity, since firing actual MANPADS at manned, flying aircraft is currently impossible to do with acceptable safety. Adding urgency to this need are the aircraft losses and near misses in Operation Iraqi Freedom and Operation Enduring Freedom caused by MANPADS, rockets, and small arms fire—threats that are becoming increasingly complex and as technologically sophisticated as the systems designed to counter them in a classic electronic warfare (EW) chess game of move and counter move. This article provides an overview of the changes in MWS and IRCM systems and the methods to test and evaluate (T&E) them.

The Old and the New

Sensors in four electromagnetic spectral bands are used by fielded MWS and IRCM systems, with some important distinctions within them that affect T&E: visual (human eye), ultraviolet (UV), infrared (IR), and radio frequency (RF) (radar). The band of sensor operation, details of sensor design, and particularly the increasingly complex algorithms using the sensor data greatly affect the T&E requirements.

For missile warning, many aircraft still use either the Mark-1 eyeball or single-pixel ultraviolet (UV) sensors (such as one of the variants of the AN/AAR-47). The AN/AAR-47 MWS sensors look for emissions from the missile plume in the UV solar-blind region of the electromagnetic spectrum, which is a roughly 50 nanometer-wide region in the spectrum where the upper atmosphere ozone layer almost completely absorbs solar radiation, making the world at ground level quite dark even in daytime. The predominant emitters in this part of the spectrum are man-made, making it an excellent spectral region to look for MANPADS guiding on an aircraft. There are also some active RF MWS, but these tend to suffer from limited detection range and high false alarm rates, aside from the obvious issue of their effect on covertness.

Flares have been used as countermeasures for half a century to decoy a MANPADS away from the target aircraft. They come in a dizzying array of shapes and sizes and with a variety of functions. In addition to free-fall "hot" flares, recent developments in MANPADS counter-countermeasures have driven the development of thrusted, covert (minimal visual signal), and area (*vs.* point source) flares. Flares can be extremely effective if the MWS provides enough warning time and the countermeasure dispenser is programmed to dispense the correct number of flares with the correct timing for the particular MANPADS targeting the aircraft. The downside of using flares is that only a limited number can be carried by an aircraft, and once dispensed, they highlight the aircraft and occasionally start fires on the ground.

Other older IRCM systems still in use consist of modulated "hot-brick" type systems (such as the AN/ALQ-144) and flash-lamp based systems. These were originally designed in the era of hot metal tracker MANPADS; they are not as well optimized for newer generation seekers that track in the mid-IR range. They also have difficulty generating high jam-to-signal ratios (without excessive weight) since they create a very broad beam of jamming energy.

In the US, several systems with significantly increased capability have been fielded in the last 10 years. The AN/AAR-57 Common Missile Warning system was fielded on US Army helicopters starting in 2004 to meet an urgent need. Soon after, the Air Force fielded the AN/AAQ-24 LAIRCM system on large fixed-wing transports (following a limited fielding of an earlier variant on SOCOM MH-53 helicopters). Both systems use five or six imaging UV sensors, which use spatial information (line-of-sight rate (LOSR) and track size) and amplitude and temporal information to discriminate missiles from clutter. The imaging capability reduces vulnerability to bright sources (just like ignoring the sun when it is in your field of view) and allows estimating whether the object being tracked shows a low LOSR as the aircraft flies (in which case the object is likely a missile using proportional navigation to guide on the aircraft) or a high LOSR (in which case it is either a missile not guiding on the aircraft or is an object fixed on the ground). The LAIRCM system (and a small number of Army CH-47 helicopters equipped

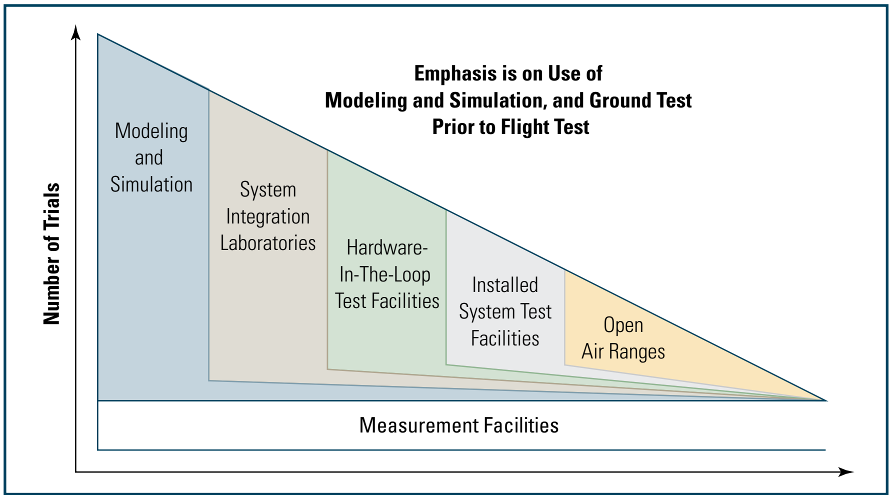

Figure 1 OSD EW Test Process [1]

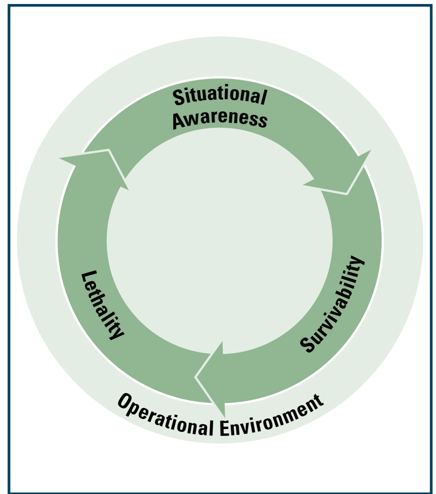

Figure 2 Evaluation structure

with the Advanced Threat IRCM (ATIRCM) system) also uses a laser-based countermeasure cued by the MWS to achieve a high jam-to-signal ratio capable of multiple modulations and spectrally matched to the typical seeker passbands.

More recently, the Air Force and Navy have developed (and the Navy has started fielding) a two-color IR missile warning system that is an upgrade to the original UV-sensor-based LAIRCM system. This system has higher resolution than the UV systems (since there is less atmospheric scattering in the mid-IR), can use the color ratio of the track intensities in the two bands as a discriminant, and with the stored digital terrain elevation data (DTED), can estimate range to tracks by projecting the look vector to where it pierces the ground. With this level of information, it is possible to use sophisticated algorithms to reduce the false alarm rate and improve the probability of declaring actual missiles.

Upgrades are being considered for all fielded MWS systems, and for new systems in development, to allow them to declare hostile unguided fire directed at the aircraft. Included in this capability is the ability to detect a range of small arms fire with or without tracers, unguided rockets, and various rocket-propelled grenades. A high fraction of recent combat engagements—but fortunately a smaller fraction of combat losses primarily thanks to vulnerability reduction efforts—have been with unguided munitions. Providing aircrew with situational awareness of engagements—allowing them to escape or turn and engage—will improve aircraft survivability.

So How Do We Test These Things?

Fundamentally, nothing has changed in the T&E of these latest systems. Proper T&E should follow the Office of the Secretary of Defense (OSD) EW test process (see Figure 1) from initial design through deployment and subsequent upgrades. What have changed are the tools to conduct this T&E. [1] Current systems are more sensitive, can produce images at a high frame rate, are coupled to highly accurate inertial platforms providing position and attitude, operate in multiple wavelength bands, can estimate range as well as angle of arrival, and have sophisticated algorithms to reduce false alarms. Smarter systems require smarter T&E.

Overview of the Evaluation Structure

The performance of an MWS and/or IRCM system can be represented by three inter-related chains of events. Figure 2 shows the linkage between situational awareness, survivability, and lethality.

The first chain of events useful for evaluating effectiveness is situational awareness (see Formula A). Improved situational awareness leads to improved survivability and is a result of a system that is more lethal (in the sense described below). The best high-level

Observe → Orient → Decide → Act

Formula A Situational Awareness

model for the evaluation of situational awareness is John Boyd's OODA-loop model. [2]

Survivability concerns the threat's kill chain. As seen in formula B below, a complete evaluation of aircraft survivability begins with evaluating the probability of the threat encountering the aircraft (PE) and continues to the evaluation of the probability of the warhead destroying the aircraft given it has hit the aircraft (PK/H). All terms after the first are conditional probabilities; aircraft survivability would be given by 1-PK/E.

$$P_{K/E} = P_E * P_{Eng/E} * P_{A/Eng} * P_{T/A} * P_{L/T} * P_{I/L} * P_{F/I} * P_{H/F} * P_{K/H}$$

E Encounter Eng Engage A Acquisition T Track L Launch I Intercept F Fuze H Hit K Kill

Formula B Survivability Chain

The third independent chain useful for analyzing effectiveness is the Lethality-Suppression or "soft-kill" chain, which are the actions taken by the MWS or IRCM system against the threat (see formula C below). While the final probability is the complement of the survivability kill chain (1-PK/E), the individual terms are quite different. The rationale for this separation is to properly apportion different test results at early stages of testing, as well as to properly place the MWS or IRCM system actions in the context of overall aircraft survivability. In situations where the EW system has a lethal effect or adjunct (cueing an anti-radiation missile, pointing a gun), there is an additional kill chain to be evaluated – Lethality-Destruction – which mirrors the threat kill chain. This kill chain

$$P_{Def/E} = P_E * P_{Det/E} * P_{T/Det} * P_{Dec/T} * P_{Cor/Dec} * P_{Loc/Cor} * P_{J/Loc} * P_{JOT/J} * P_{Def/JOT}$$

E = Encounter, Det = Detect, T = Track, Dec = Declare, Cor = Correlate, Loc = Locate, J = Jam, JOT = Jam on target, Def = Defeat.

Formula C Lethality-Suppression Chain

resembles that for survivability above, but from the aircraft versus the threat perspective.

All analyses of a system's performance must include an analysis of its suitability. In order to be effective, the system must function in its natural and man-made environment. Suitability, including reliability, availability, and maintainability, should be evaluated on an equal basis with system effectiveness throughout the development of the system.

Specific Examples of Testing

The areas in which MWS and IRCM system T&E have changed the most, and thus made the greatest impact on test resources, are: closed loop testing (hardware-in-the-loop (HITL) and installed system test facility (ISTF)) and open-loop testing at Open Air Ranges (OAR). These are the last three steps of the OSD EW test process.

Open-Loop Testing at Open Air Ranges

All but the first and last links in the lethality-suppression kill chain (probabilities of engagement and defeat given jamming on target) can be evaluated using missile plume simulators at an OAR. For these tests, lamps or other sources with the proper spectral, spatial, and temporal signature are used to generate the signature of a missile plume closing on the aircraft. Proper missile plume signature generation is a complex process, requiring high fidelity simulators that are properly calibrated and have sufficient maximum radiant intensity to represent the missile plume signature in the MWS bands. The signatures collected at live fire tests must be scaled using atmospheric, missile fly-out, and plume models to take into account current atmospheric conditions, atmospheric loss as the simulated missile closes on the target aircraft, and the sensitivity, bandwidth, and aperture of the MWS or IRCM sensor. Previous practice was to use stimulators that produced a signal that caused the MWS to declare but did not represent an actual properly scaled missile plume signature. While useful for confirming MWS integration and aircrew reactions to missile alerts, this stimulation of the MWS is not useful for testing MWS performance.

Traditional plume simulators are ground-based. The current state-of-the-art system is the JMITS system (see Figure 3) operated by the Center for Countermeasures, which has a wide range of UV and IR lamps, an aircraft tracking capability, and radiometers for measuring laser jammer energy. However, modern MWS systems are able to measure range to tracks, which is used as a discriminant between actual missiles (or a missile of interest) and false tracks. This causes JMITS to be rejected if the aircraft flies too close to it and/or the line of sight to JMITS from the aircraft changes at too high a rate. This has led to a second type of plume simulator, the towed airborne plume simulator (TAPS) (see Figure 4). TAPS is a towed pod containing a mix of pyrophoric liquids; when the liquid is dispensed into the airstream, it spontaneously burns. By towing it on a parallel flight path to the test aircraft and regulating the flow of liquid to simulate both the intrinsic change in plume intensity and the apparent change in intensity of a simulated missile closing on the test aircraft, TAPS presents MWS systems with a signature with proper line of sight rate, proper intensity over time, and proper color ratio (by adjusting the mix of liquids). This signature is also presented against an appropriate clutter background. Currently, the color ratio is fixed for the entire mission, rather than varying over the burn time of a missile; an upgrade to TAPS is being considered to correct this.

While the focus on much of MWS and IRCM system testing is their ability to declare and counter actual missiles, an equally important consideration is that they do not declare a missile that is not there. Depending on how the systems are mechanized, false alarms can cause needless flare dispenses, or cause the laser jam turret to slew unnecessarily, which occupies the jammer and prevents it from countering a real missile at the same time, and causes additional wear on the jammer turret. To provide a baseline of performance, two related types of tests are done (following substantial design and modeling work done earlier to minimize false alarms while maintaining an acceptable probability of timely declaration). The aircraft can fly set routes over a mix of rural, suburban, urban, and industrial areas to examine the susceptibility of the system to random clutter (trolling tests). A consistent comparison in MWS performance can be made by flying the same route over a short period of time, by flying multiple aircraft with different MWS systems on the same route, or by normalizing different routes by characterizing their potential to cause

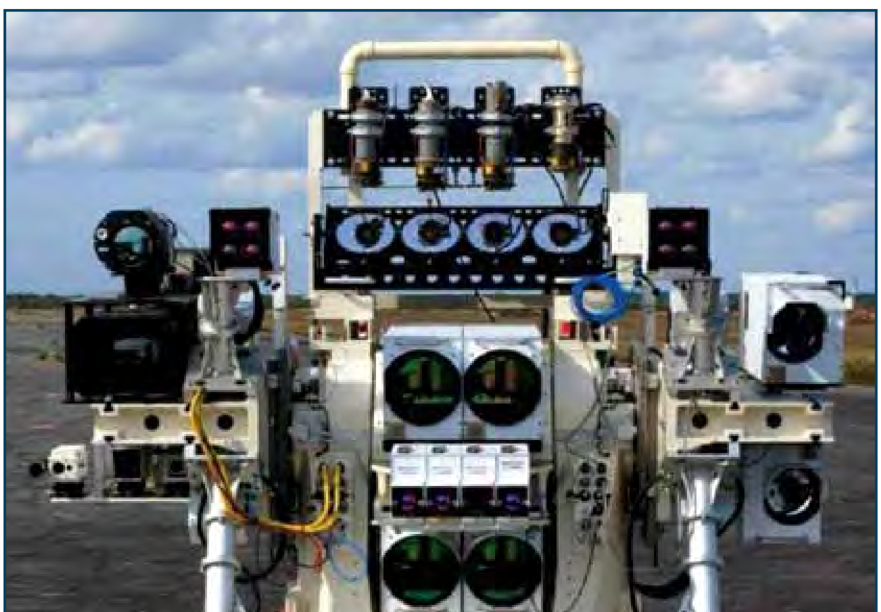

Figure 3 JMITS Missile Plume Simulator with captive seekers

false alarms. As part of this, or as part of a separate dedicated test, additional potential false alarm sources (PFAS) can be included in the route, including gun fire (of various calibers), rocket and other weapon fire, flare dispenses, and ground fires (PFAS tests).

Closed Loop Testing at HITLs, ISTFs, and OARs

OAR. There are several ways to determine the effectiveness of an IRCM technique against threats. Captive seeker tests are a common form of OAR flare effectiveness testing used for years. Nearly all the actual hardware and environmental effects are present for such tests; however, since the seekers are ground mounted in test vans, the missiles do not close on the aircraft during an engagement, and the linear extent of the seeker field of view is only correct for the actual range to the aircraft—it does not shrink as it would for an actual missile closing on a target aircraft. There are also no dynamic effects of missile motion, and a test engagement begins when the flare is dispensed, rather than when at the time a missile would be launched,

HITL. HITL laboratory testing is one way to get higher fidelity missile motion and field of view, but at the cost of lower fidelity aircraft signatures and environment and installation effects. However, most IR scene generators have insufficient dynamic range to create aircraft signatures and flares at the same time. Or they require a complex optical path to combine several images and a laser jammer and/or flare signal into missile seeker optics. An alternative more cost-effective solution is a threat system processor in the loop (SPIL). In a SPIL, the IR scene, target, and IRCM are generated digitally and optically convolved with the seeker optics and reticle using digital signal processing. This results in a signal that can be directly injected into the threat processor. The guidance commands can be taken directly from the processor and used to update the position of the missile in the fly-out model. The primary limitation is the speed of the digital signal processing, which is currently near the lower limit of the requirement.

Figure 4 Towed Airborne Plume Simulator (TAPS) prior to deployment

ISTF. Traditionally, testing at an ISTF is the first time the system under test is installed and tested in the intended airframe. Integration issues that require the full aircraft avionics suite, as well as the effects of installation on obstruction of sensor field of view, are tested here. For a missile warning system, this is not usually particularly high risk, but there are several tests that require this sort of facility. Developing the aircraft obstruction map so the MWS knows when the airframe will obstruct it or when the rotors might be in the sensor field of view is crucial. Aircraft electromagnetic interference tests are best performed with a completely installed system to determine sensitivity to external interference or strong RF signals experienced during shipboard operations.

OSD is funding an ISTF capability that blurs the lines between HITL and ISTF; it is known as Joint Distributed IRCM Ground-test System (JDIGS). It was funded to address seven of the 12 outstanding Joint Test Resource Needs Statements (TRNS) identified by the IRCM Test Resource Requirements Study (ITRRS) (see discussion on ITRRS below). There are several phases and builds to this project. The initial build will be intended for testing MWS systems only, while the second build will enable testing of Distributed IRCM (DIRCM) systems and flares. It will include IR/UV scene generation and projection to each sensor, a manned flight simulator, simulated aircraft flight, real-time closed loop missile fly-out, free-space monitoring of DIRCM output, and linkage to other HITL facilities that can do closed-loop threat testing. Should the latencies to the external sites prove too great, the Navy will build SPILs at the central site.

Future Test Resource Needs

In 2006, ITRRS was created to identify and propose solutions to test resource shortfalls for the testing of Electro-Optical/IR systems. ITRRS used a careful methodology starting with draft test requirements, refined them through a series of workshops and surveys of potential users to develop test resource needs, and then developed proposed solutions that were prioritized to produce a roadmap endorsed by DTRMC to address the identified shortfalls. The ITRRS approach is for users to develop documented needs, and test facilities to suggest solutions to meet those needs.

ITRSS identified 12 test resource shortfalls that range from standard models and scene generation to improved surrogate aircraft. The ITRRS emphasis is on common solutions to the shortfalls that allow sharing of data collected with similar assumptions and between test phases.

JMITS was the result of an earlier process to identify IRCM test needs, and TAPS, JDIGS, and the Multi-Spectral Sea and Land Target Simulator are examples of programs that have resulted from ITRSS.

A number of the ITRRS test resource shortfalls remain unfilled, the hostile fire indication capability that all MWS systems are attempting to incorporate requires new and different resources, and new generation MWS and IRCM systems will continue to require smarter T&E capability that more closely mimics actual missile launches. ■

References

1. A Description of the DoD Test and Evolution Process for Electronic Warfare Systems, Revision 2; Director, Test, Systems Engineering, and Evaluation, Office of the Under Secretary of Defense (Acquisition and Technology); 31 July 1996.
2. John Boyd, Discourse on Winning & Losing, briefing undated.

AH-64D Apache Longbow Helicopter Live Fire Ballistic Vulnerability Testing

by Andrew Bajko and Frederick Marsh

The product of the Apache modernization program, the AH-64D Apache Longbow (shown in Figure 1) is an upgraded version of the AH-64A Apache attack helicopter. Primary modifications to the Apache were the addition of a millimeter-wave fire control radar (FCR) target acquisition system, the fire-and-forget Longbow HELLFIRE air-to-ground missile, updated T700-GE-701C engines (for FCR-equipped Apache Longbows), and a fully integrated cockpit. In addition, the aircraft received improved survivability, communications, and navigation capabilities. McDonnell Douglas Helicopter Systems (now part of the Boeing Company) delivered the first AH-64D to the Army in March of 1997.

Figure 1 AH-64D Apache Longbow Helicopter

Congressionally mandated Live Fire Test and Evaluation (LFT&E), which was conceived in 1986 to address critical vulnerability and lethality issues for armored vehicles, is regulated by the Live Fire Law provisions in Title 10 of the US Code, Section 2366. In 1987, the Live Fire Law was updated to include all major conventional land, air, and sea systems, as well as all major munitions and missile programs. Accordingly, the AH-64D system was a "covered" product improvement and was required to undergo LFT&E prior to full-rate production decision; the AH-64D was the first Army helicopter to undergo LFT&E. The Live Fire Law mandates full-up system-level (FUSL) testing on a production-representative asset unless such testing would be "unreasonably expensive and impractical." The Office of the Secretary of Defense granted the AH-64D a waiver from FUSL testing in 1994. In lieu of FUSL testing, an alternate LFT&E program was developed, which consisted of a combination of subsystem-level testing on partial AH-64 assets, system-level testing on a remanufactured/upgraded AH-64A ground test vehicle (GTV), prior ballistic test data, modeling and simulation, and quantitative analyses to evaluate the aircraft's vulnerability.

A primary element of the LFT&E process is the evaluation of the impact of each subsystem upgrade to ballistic vulnerability. Key phases leading to the identification of AH-64D Live Fire test areas were (1) a threat review, which identified the priority threats for a detailed ballistic vulnerability assessment, and (2) a detailed ballistic vulnerability assessment. In addition to quantifying the vulnerability estimates for the AH-64D system, an objective of this assessment was identification of vulnerability issues and information voids, along with recommendations for their resolution in conjunction with LFT&E. In 1995, a series of Live Fire vulnerability tests were executed by the Survivability/Lethality Analysis Directorate (SLAD) of the US Army Research Laboratory (ARL), the Army organization designated to conduct Live Fire testing of aviation systems. The program included ballistic testing of the mast-mounted assembly (MMA) and the hydraulic subsystem. The only AH-64D subsystem not tested in 1995, and which was also identified under the vulnerability LFT&E requirements of the Test and Evaluation Master Plan (TEMP), was the engine compartment fire detection and suppression system (FDSS). As stated in the TEMP and its associated LFT&E Independent Evaluation Plan/Test Design Plan, testing of the FDSS was postponed due to an ongoing effort to find a replacement for the Halon 1301 fire-extinguishing agent. As of 2003, no alternative agent had been identified by the Army. At this time, in addition to addressing the vulnerability of the FDSS, the Army assembled a vulnerability integrated product team (IPT) to conduct a review of changes to the AH-64D system (since 1995) that could affect vulnerability. During their review, the IPT determined that the only change that could potentially affect the vulnerability of the aircraft was the addition of the internal auxiliary fuel system (IAFS) Combo Pak (the Combo Pak combines a fuel storage tank and an ammunition magazine storage container into one assembly). From 2004 to 2005 the FDSS and the IAFS Combo Pak were evaluated with ballistic and non-destructive tests conducted by SLAD.

Mast Mounted Assembly Test (1995)

MMA testing examined the assembly's tolerance to ballistic damage mechanisms and potential cascading effects of that damage on the helicopter system.

To isolate the damage characteristics of the MMA from other system interactions, testing began with firings against an off-aircraft MMA. These technical tests were followed by shots against an MMA installed on a restrained, remotely operated AH-64A GTV. Although the GTV was fundamentally an A-model, key subsystems/components were fully representative of a production AH-64D, including the MMA, rotors, flight controls, and engines. The shots were conducted while the GTV was operating under simulated hover or forward-flight conditions, with engines running, rotors turning, and controls powered (see Figure 2). Forward-flight conditions were simulated by employing an airflow generation system (capable of creating airflow in excess of 100 knots) to discharge air onto the GTV.

Tests targeted the MMA (radome) and its lightweight de-rotation unit with small caliber munitions and provided data for assessing MMA structural integrity, debris generation and effects on continued aircraft operation, and fire control radar functionality following a ballistic impact.

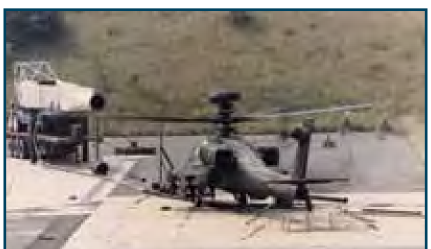

Figure 2 Mast Mounted Assembly Test on AH-64D Apache Longbow GTV (1995)

Hydraulic Subsystem Test (1995)

Hydraulic subsystem testing examined the ballistic vulnerability of components located in the mid-aft fuselage region. Testing consisted of a series of shots into AH-64A test articles—the mid-aft fuselage sections. The sections were refurbished to replicate a structurally correct AH-64D mid-aft fuselage and included configurationally correct, mounted, and pressurized D-model primary and utility hydraulic subsystems.

The shots targeted the primary and utility hydraulic lines and provided data for assessing the effectiveness of the armor-shielding portions of the subsystem, the extent of subsystem degradation, the corresponding effects on continued main and tail rotor control, and the likelihood of igniting a fire fueled by leaking hydraulic oil (see Figure 3).

Figure 3 AH-64D Apache Longbow Hydraulic Subsystem Test (1995)

Fire Detection and Suppression System Test (2004 to 2005)

FDSS testing investigated vulnerability to engine compartment fires initiated by small caliber munitions. To examine various factors which influence the likelihood that a sustained engine compartment fire would occur, testing began with a series of component/subsystem-level ballistic firings and controlled damage tests. These tests were followed by a series of shots against a remotely operated, pre-production AH-64D GTV. Shots against the GTV and the majority of the controlled damage tests were conducted while the GTV was operating under simulated hover-flight conditions.

The following list describes FDSS test phases and objectives—

- **Phase 1:** Ballistic firings targeting engine compartment structural components (*e.g.*, skin, framing) and engine fuel components examined the likelihood that the projectile's incendiary would function and provide a fire ignition source. These tests were conducted off-aircraft using salvaged components, thereby preserving the GTV for subsequent testing (see Figure 4).
- **Phase 2:** Engine compartment drainage tests examined compartment drainage characteristics and identified compartment areas where leaking fuel might pool and sustain a fire.

Figure 4 Projectile Functioning Test Article

- **Phase 3:** Hot surface ignition tests were conducted to investigate the likelihood that heated engine surfaces could potentially ignite leaking fuel. To simulate fuel leaks that may result from a ballistic impact, remotely controlled valves leading to discharge nozzles were installed on engine fuel components. This enabled JP-8 fuel to be leaked from the fuel component onto the engine surfaces while the GTV was operating.
- **Phase 4:** Spark-induced ignition tests were executed to examine fuel fire propagation characteristics and FDSS effectiveness in detecting and suppressing engine compartment fires (see Figure 5). To simulate fuel leaks that may result from a ballistic impact, remotely controlled valves leading to discharge nozzles were installed on engine fuel components. To simulate the ignition source provided by incendiary projectile impact, remotely operated spark generators were installed in proximity

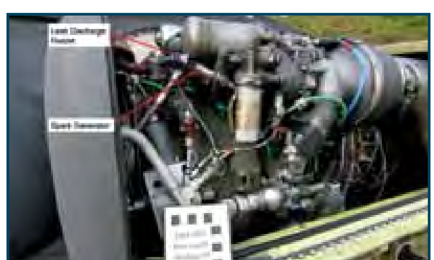

Figure 5 FDSS Spark-Induced Ignition Test

to the fuel discharge nozzles. This enabled on-command fuel fire ignition during GTV operation.

- **Phase 5:** Shots against the operating GTV targeted engine fuel components and provided data for assessing ballistically induced fire ignition and fire propagation, FDSS effectiveness in detecting and suppressing fire, and propulsion subsystem performance following a ballistic impact to an engine (see Figure 6).

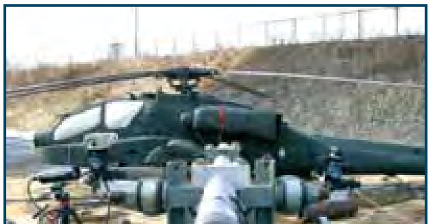

Figure 6 FDSS Test on AH-64D Apache Longbow GTV

Figure 8 IAFS Combo-Pak Testing - Installed In AH-64D GTV

Internal Auxiliary Fuel System Test (2005)

IAFS Combo Pak testing investigated AH-64D vulnerability to ballistic impacts to its IAFS Combo Pak. Specific issues included the ballistic tolerance of the fuel and ammunition components and potential for ballistic initiation of fire.

Testing consisted of ballistic firings against an off-aircraft Combo Pak and a series of shots against a Combo Pak installed in an operating pre-production AH-64D GTV.

The off-aircraft firings targeted ammunition components and provided data for assessing fire ignition potential, destructive ammunition reactions, and ammunition feed system functionality (see Figure 7). Shots against the GTV targeted Combo Pak fuel components and provided data for assessing fuel tank self-sealing performance, hydrodynamic ram damage effects, the potential for dry bay fire initiation, and fuel subsystem functionality following a ballistic impact (see Figure 8).

Figure 7 IAFS Combo-Pak - Instrumented and Mounted On Ballistic Test Stand

Future Efforts

The AH-64D continues to undergo upgrades to increase operational readiness and effectiveness. The latest upgrades planned for this platform have been designated as the Block III Apache. An alternative LFT&E strategy has been developed for the Block III that will include additional Live Fire testing focusing on vulnerability issues associated with upgraded/modified components and their systems.

Summary

In conclusion, AH-64D enhancement programs will allow the now battle-proven Apache Longbow to remain a viable asset for Army forces. Results of AH-64D LFT&E identified critical component and subsystem ballistic vulnerabilities and will aid in developing solutions to improving survivability on future battlefields. ■

JCAT Corner

Continued from page 5

Due to the deployment cycle the JCAT experienced a turnover in personnel at all three operating locations in Afghanistan. At Camp Leatherneck/Bastion (RC-Southwest) CDR Craig Fehrle was replaced by CAPT Bill Little as the theater Officer-in-Charge (OIC), and LT Oral John was replaced by LT Jim McDonald; Maj Dave Garay replaced Maj Mark Friedman at Kandahar (RC-South); and Maj Nick Hardman replaced Maj Rich Lopez at Bagram (RC-East). The outgoing JCAT'ers performed superbly and set high standards for their replacements to achieve.

In addition to personnel changes with the deployed JCAT, the Continental US JCAT experienced some changes in leadership also. First, congratulations to CW4 Michael Kelley upon his promotion to CW5 and selection as lead for the Army JCAT/Aircraft Shoot-Down Assessment Team. CW5 Kelley replaces CW5 Bobby Sebren who is on deployment in Afghanistan; LtCol Chuck Larson replaces LtCol Dave Bartkowiak as the Air Force JCAT lead; and CAPT Bill Little replaces CAPT Kirby Miller as Navy JCAT/Combat Aircraft Survivability and Threat Lethality (CASTL) mission lead. Additional congratulations go out to CDR Tim Johnson who replaces CAPT Cliff Burnett as the CASTL Det. A OIC and CDR Dave Storr replaces CDR Kevin Askin as the CASTL Det. B OIC. A final note of congratulations goes to CAPT Miller and the CASTL organization upon their selection as the NAVAIR Reserve Program (NRP) Unit of the Year. Under CAPT Miller's exemplary leadership this is the second consecutive year the CASTL has received this honor.

Be sure to keep early spring open on your calendar to attend the 2011 version of the annual Threat Weapons and Effects Training Seminar which will be held 26-28 April at Hurlburt Field, FL. The Navy component of the JCAT has the lead for coordinating this year's event. The theme is "Back to the Future" which will include the nature of airborne challenges in a Korean area of responsibility, as well as operations in Afghanistan among many other informative topics. There will be weapons demonstrations, displays, and other interesting events to view also. We hope to see you there in April! ■

COMMANDER
NAVAL AIR SYSTEMS COMMAND (4.1.8J)
47123 BUSE ROAD
PATUXENT RIVER, MD 20670-1547

Official Business

Calendar of Events

APR

52nd AIAA/ASME/ASCE/AHS/ASC Structures, Structural Dynamics
4–7 April 2011
Denver, CO
http://www.aiaa.org/content.cfm?pageid=230&lumeetingid=2412

27th National Space Symposium
11–14 April 2011
Colorado Springs, CO
http://www.nationalspacesymposium.org

AAAA Annual Convention
17–20 April 2011
Nashville, TN
http://quad-a.org/index.php?option=com_content&view=article&id=330&Itemid=67
aaaa@quad-a.org

21st Annual Advanced Technology Electronic Defense Systems (ATEDS) Conference
19–21 April 2011
San Diego, CA

JCAT Threat Weapons Effects Seminar
26–28 April 2011
Hurlburt Field, FL
http://www.bahdayton.com/jcat2011

MSS Electro-Optical (EO) and Infrared Countermeasures (IRCM)
26–28 April 2011
Monterey, CA

MAY

Reinventing Space Conference 2011
2–6 May 2011
Los Angeles, CA
http://www.responsivespace.com/Conferences/RS2011/RS2011.asp

11th Annual BlazeTech Course: Aircraft Fire and Explosion – Protection Against Accidents and Combat/Terrorist Attacks
3–6 May 2011
Woburn, MA
http://www.blazetech.com/firecourse.html

Aircraft Combat Survivability Short Course
17–20 May 2011
Monterey, CA
http://www.bahdayton.com/jaspsc

30th International Space Development Conference (ISDC)
18–22 May 2011
Huntsville, AL
http://isdc.nss.org/2011/index.shtml

JUN

ArmorCon Military Armor Exhibition & Conference
6–9 June 2011
Vienna, VA
http://www.armorconexpo.com/Event.aspx?id=443630

Live Fire Test & Evaluation Conference
6–9 June 2011
Eglin, AFB
http://www.ndia.org/meetings/1390/Pages/default.aspx

2011 International Applied Reliability Symposium (ARS)
7–9 June 2011
San Diego, CA
http://www.arsymposium.org/northamerica/index.htm

NSA SIGINT Development Conference 2011
7–8 June 2011
Ft. Meade, MD
http://www.fbcinc.com/event.aspx?eventid=Q6UJ9A00P59E

2011 National Space & Missile Materials Symposium (NSMMS)
27 June–1 July 2011
Madison, WI
http://www.usasymposium.com/nsmms/default.htm

Information for inclusion in the Calendar of Events may be sent to:

SURVIAC, Washington Satellite Office
13200 Woodland Park Road, Suite 6047
Herndon, VA 20171