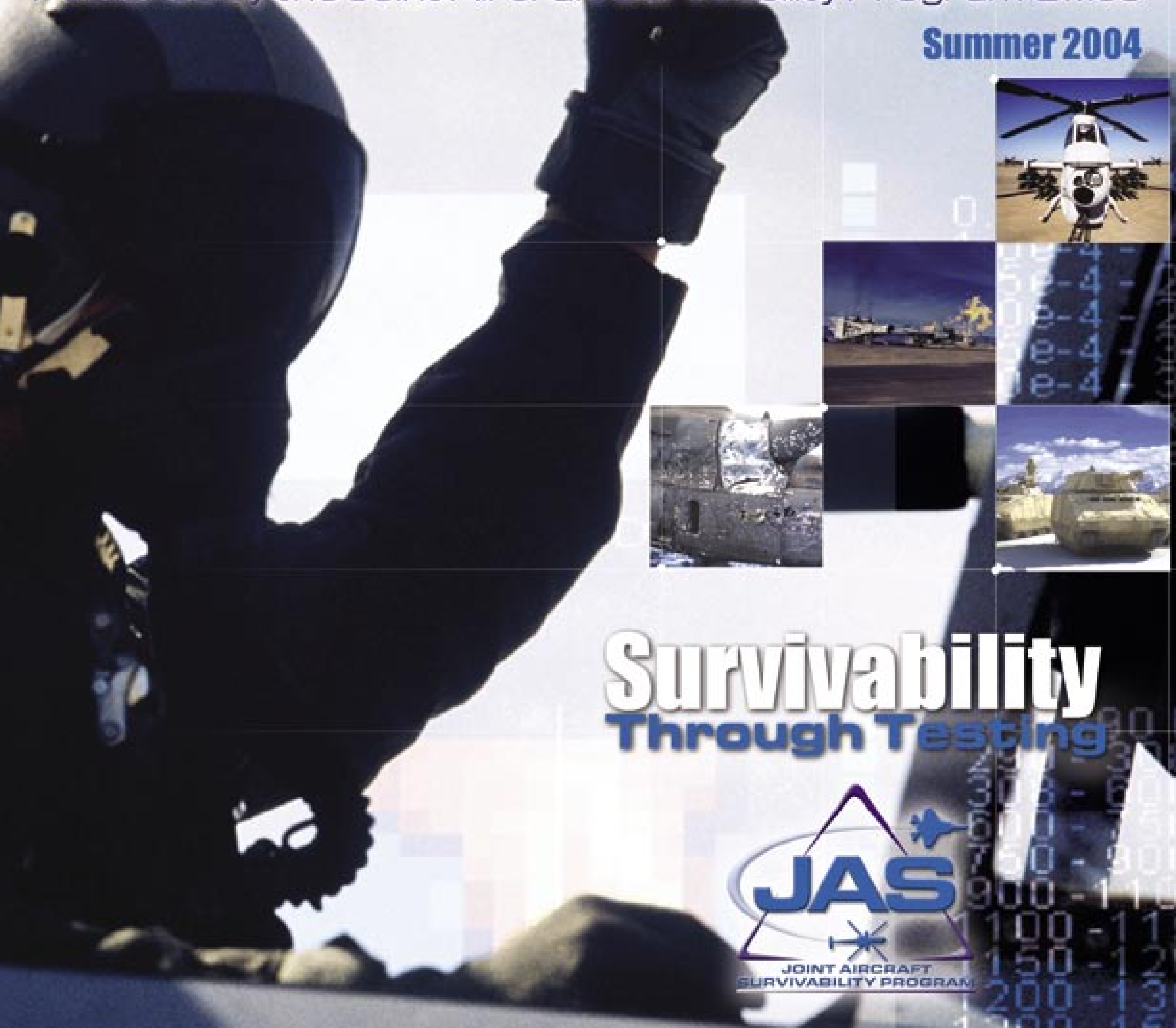
AIRCRAFT SURVIVABILITY

Published by the Joint Aircraft Survivability Program Office

Summer 2004



Survivability Through Testing

JAS
JOINT AIRCRAFT SURVIVABILITY PROGRAM

Aircraft Survivability is published three times a year by the Joint Aircraft Survivability Program (JASPO). The JASPO is chartered by the Joint Aeronautical Commanders Group.

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About the Cover

This issue's cover reminds us that for manned aircraft, the pilot benefits from flying a more survivable aircraft. Testing is an integral part of achieving a design with optimum survivability characteristics. This issue focuses on testing and depicts the pilot's safe return from battle, ready to fight another day.

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Distribution Statement A:
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News Notes

■ *by Mr. Joseph Jolley*

Figure 1. Mr. Larry Eusanio (middle) proudly displays his AIAA Survivability Award. He is accompanied by his wife Marilyn and Dale Atkinson..

Larry Eusanio receives AIAA Survivability Award

Mr. Larry Eusanio, who is the Project Leader for Air Systems Live Fire Test & Evaluation (LFT&E) at the Institute for Defense Analyses (IDA) in Alexandria, Virginia, received the American Institute of Aeronautics and Astronautics (AIAA) Survivability Award at the 45th AIAA Structures, Structural Dynamics, and Materials Conference held at the Wyndham Palm Springs Hotel in Palm Springs, California on April 21, 2004 in conjunction with the AIAA Survivability Technical Committee meeting held at the same time. The Survivability Award is presented every two years to an individual or a team to recognize outstanding achievement or contribution in design, analysis, implementation, and/or education of survivability in an aerospace system. Mr. Eusanio's citation read, "In recognition of his analytical efforts and program leadership that have improved the survivability of many U.S. military aircraft currently in the defense inventory or in the acquisition process." IDA supports the Director of Operational Test & Evaluation (DOT&E) in the Office of the Secretary of Defense in survivability matters.

Key Personnel Changes

VADM Walter B. Massenburg takes over as chairman of the JACG

At the Joint Aeronautical Commanders Group (JACG) meeting January 14, 2004, VADM Massenburg assumed Chairmanship of the JACG. VADM Massenburg is the Commander, Naval Air Systems Command located at Patuxent River, Maryland. The JASPO is chartered by the JACG. The purpose of the JACG is to develop and continuously improve joint processes and procedures that will facilitate the design, development, and acquisition of aviation systems (i.e., aviation platforms, subsystems, weapons, and support systems) that are identical or, to the maximum extent possible, common, and that maximize interoperability.

Ken Goff takes over as Navy Principal Member of the JASPO Principle Members Steering Group (PMSG)

At the JASPO Principal Members Steering Group meeting held in Orlando, Florida January 27–29, 2004, Mr. Ken Goff replaced Mr. Tim Horton as the JASPO Navy Principal Member and Chairman of the Principal Members Steering Group (PMSG). The PMSG oversees the actions of the JAS Program Office and has overall approval authority for all JASPO activities. Mr. Goff is both the National Director of the Survivability Engineering Division and the Head of the Survivability Engineering Division (AIR–4.1.8) (Site Leader), Naval Air Systems Command (NAVAIR), Patuxent River, Maryland. He has worked for NAVAIR for 20 years. Ken has long been involved in the JASPO and its predecessor, the JTCG/AS. We welcome Ken on board in his new role as Chairman and Navy Principal Member.

LCDR Dan Chisholm is the new JASPO program manager

On January 5, 2004 LCDR Dan Chisholm became the new JASPO Program Manager replacing CDR Andy Cibula. LCDR Chisholm is a naval aviator with over 2,000 hours in the EP–3/P–3 aircraft. He holds a masters degree in Mechanical Engineering from the Naval Post Graduate school. LCDR Chisholm's most recent assignment was with the National Reconnaissance Office (NRO). He was re-designated an Aerospace Engineering Duty Officer (AEDO) in September 2001. We welcome Dan onboard and look forward to working under his leadership.

LCDR Dan Chisholm
Program Manager for JASPO

Mr. Dennis Lindell
Deputy Program Manager
for Vulnerability Reduction

Dennis Lindell joins JASPO staff

Mr. Lindell came to the JASPO in November 2003. Prior to that, he served as the Survivability/Lethality Analysis Directorate (SLAD) liaison to the office of the Deputy Undersecretary of the Army for Operations Research. Mr. Lindell received his B.S. in Aerospace Engineering and Mechanics from the University of Minnesota in 1988. He worked in the field of helicopter vulnerability test and analysis at the U.S. Army Research Laboratory, Survivability Lethality Analysis Directorate (ARL/SLAD) from 1989 to 2003. Dennis is the Deputy Program Manager for Vulnerability Reduction.

JASPO gets new administrative assistant

In February 2004, Ms. Jami Johnston replaced Ms. Jennifer Willie as the JASPO administrative assistant. Ms. Johnston comes from OSD/DOT&E where she was administrative assistant in the LFT&E office. We welcome Jami to the JASPO. Ms. Willie did an outstanding job during her tenure with the JASPO. She has accepted a position as technical writer with the Department of Homeland Security.

Federal Aviation Administration (FAA) to order U.S. airlines to install fuel inerting system on aircraft

From the Washington Post newspaper dated February 18, 2004, the FAA said it will order U.S. airlines to install a fuel inerting system on thousands of planes to prevent fuel tank explosions. The need to develop a fuel inerting system stems from the National Transportation Safety Board's ruling that a center-wing fuel tank explosion likely caused the destruction of Trans World Airlines flight 800 in July 1996.

The JASPO played a large part in developing a similar system for application in military aircraft. OBIGGS (On-board Inert Gas Generating System) is installed on the following aircraft: C–17, F/A–22, V–22 and AH–64. OBIGGS is also being considered for the MH–60K, MH–47E, F–35, AH–1Z and UH–1Y.

JCAT team in Iraq

The Commanding General of the 3rd Marine Air Wing (MAW) recently issued a message requesting the Joint Combat Assessment Team (JCAT) to deploy to Iraq in support of Operation Iraqi Freedom (OIF) II. Currently, the JCAT is comprised of USAF and USN reserve personnel. Lt Col Tony Brindisi, USAFR and CAPT Gary Tollerene, USNR are now deployed. Plans are in place for the U.S. Army to join JCAT in the near future. The JCAT mission is to capture perishable data on coalition fixed and rotary wing aircraft combat damages and losses. They will conduct inspections and forensic analysis of combat damaged aircraft and incident sites; as well as interview aircrew, intelligence, weapons and tactics, and logistics personnel. Based on this data, they will provide operational commanders the accurate threat weapon data needed to change Tactics, Techniques, and Procedures (TTPs) to mitigate the threat. This will increase the operational commanders awareness of the threat weapons that are inflicting damage on coalition assets in real-time and allow adjustment of TTPs as necessary.

National student design project accents aircraft survivability

The American Institute of Aeronautics and Astronautics (AIAA) Foundation sponsors seven annual design competitions, offering the opportunity for undergraduate and graduate students to work either individually or in teams to solve real-world aerospace problems. This year's national undergraduate team aircraft design competition will involve the design of an "Advanced Gunship," encouraging student teams across the U.S. to design a modern replacement for the C–130 gunship. In the "Opportunity Description" (similar to a request for proposals), the AIAA is strongly encouraging the consideration of aircraft survivability features in the design of the Advanced Gunship—the second sentence in the Opportunity Description reads:

"*The key feature is to achieve high survivability versus low cost threats (Anti-Aircraft Artillery—AAA and Man-Portable Air Defense Systems —MANPADS). And the number one General Design Requirement is: highly survivable versus advanced MANPADs and AAA threats.*"

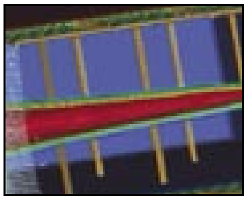
"This is a great opportunity for students to be exposed to aircraft survivability as an integral part of the design process," stated study leader Robert E. Ball, distinguished Professor Emeritus of the Naval Postgraduate School, and author of The Fundamentals of Aircraft Combat Survivability Analysis and Design, now in it's second edition.

For more information, contact Chairman Mike Weisenbach at 703.607.3509 or via e-mail at michael.weisenbach@navy.mil.

NDIA Combat Survivability Division executive board chairman to step down

At the executive board meeting held May 18, 2004, the Chairman, RADM Bob Gormley, USN Ret., announced he will step down as division chairman and resign from the board December 2, 2004, after the NDIA Survivability Symposium in Monterey, California, November 30 –December 2, 2004. He said his decision to step down was for personal reasons and that he believed this is the right time to effect a change in leadership.

ADM Gormley has done an outstanding job as an advocate for aircraft combat survivability. Under his leadership, the Combat Survivability Division in the NDIA enjoys a good reputation and is recognized for its successful symposiums and workshops.



Innovation in the C–5 LFT&E Program

■ *by Lt Stephen N. Sacovitch and Mr. Alex G. Kurtz*

Merriam Webster defines innovation as "the introduction of something new; a new idea, method, or device." Using innovation as our motto, the C–5 live fire test and evaluation (LFT&E) program has developed a test program that will answer questions through a variety of new avenues. The C–5 LFT&E program is associated with the C–5 Modernization Program, which includes the Avionics Modernization Program (AMP) and the Reliability Enhancement Re-Engining Program (RERP). This modernization program is based out of Wright-Patterson AFB within the Mobility System Program Office, the C–5 Development System Office, also known as the C–5 DSO (ASC/GRA).

DoD 5000.1 Para 4.3.3 policy states "acquisition professionals shall continuously develop and implement initiatives to streamline and improve the DoD Acquisition System. Program managers shall examine and, as appropriate, adopt innovative practices…that reduce cycle time and cost and encourage teamwork."

Under the keen leadership of the former C–5 LFT&E Program Manager, 1st Lt Joseph E. Robertson, the team used this guidance to create a unique program, focusing on teamwork, innovation in cost, and incorporation of ideas and tests that address the vulnerability of this heavy airlift aircraft.

Innovation in cost

Cost being a critical driver in any acquisition program, a logical question would be—what was unique in this program concerning cost and LFT&E? First, the program has a $20M cost cap. This makes cost an independent variable, bounding program total cost and ensuring that the highest priority LFT&E activities are accomplished. Additionally, this cap provides a forum for open discussion of program priorities (test and analysis). When everyone's cards are on the table, it is easier to make trades on these priorities. This approach facilitates better relations between the Service and OSD/DOT&E since we all are bound to a "$20M pie" and its respective allocations. Together, we have built a consensus on priorities that can live up to Congressional scrutiny.

Innovation in teamwork

This teamwork-oriented approach is central to the innovations of our LFT&E program. We want to ensure that our focus is always on the customer. As with any successful business, customer focus serves to build the team. Our view of DOT&E as "the customer," not an adversary, has given us a great deal of success. Putting program relationships into a customer-supplier perspective helps us to focus on managing DOT&E's expectations. This has encouraged open communications and built on the teamwork idea. DOT&E is invited to and participates in many of our meetings, assisting us with our schedule and providing guidance. This teamwork idea is not new, but is essential to program success. With the financial cap, consistent DOT&E involvement is considered key to program success and prevents our customer from being surprised.

To piggyback the teamwork it was essential for us to collaborate with the best experts throughout the program and include C–5 operators in the early stages and along the LFT&E path. We have combined a variety of experts to work on our C–5 LFT&E team which include—Operation Analysis Branch of the Aeronautical Systems Center's Engineering Directorate (ASC/ENMM–WPAFB, Ohio), the Aerospace Survivability and Safety Flight of the 46th Test Wing WPAFB, Ohio (46th TW/AVSF), the Guided Weapons Evaluation Facility of the 46th Test Wing Eglin AFB, Florida (46th TW/GWEF), LM Aero Marietta Georgia, the Air Force Research Labs at Hanscom AFB, Massachusetts (AFRL/VSBT), the Naval Air War Center – China Lake, California (NAWC), and the C–5 Aircraft Systems Experts, Dover AFB, Delaware.

The test communities are not the only ones included on our LFT&E team. We have also pulled the C–5 operators from Air Mobility Command (AMC) at Scott AFB, and the sustainment community, C–5 SPO at Warner-Robbins AFB, Georgia. This was essential since our results are designated to go beyond full rate production milestones and may affect future tactics and procedures.

Additionally, many survivability/vulnerability products can be used for follow-on activities, and benefit warfighters in the field and potentially transition to other platforms. This will include a C–5 SPIRITS model, updated target descriptions, survivability improvement recommendations, zonal cargo and passenger study results, and MANPADS study results.

Innovations in testing

Several of our trials will include an innovative combination of destructive and non-destructive testing. Our fire suppression, ullage, avionics, and auxiliary power unit (APU) QT&E non-destructive tests all answer LFT&E issues without performing ballistic tests or destroying one-of-a-kind assets. These are crucial because many of these non-destructive tests/trials save money and free up funding for doing the highest priority ballistic tests.

In a unique approach to the problem, we were able to answer both LFT&E and safety issues by using the latest Federal Aviation Administration-endorsed methodology. The use of the Uncontained Engine Debris Damage Assessment Model (UEDDAM) allowed the program to realize large cost savings while answering vital questions about the safety and vulnerability of the upgraded engines due to cascading damage.

We are also taking advantage of the Guided Weapons Evaluation Facility (GWEF) at Eglin AFB, Florida, to accomplish non-destructive testing. We are assessing the C–5's vulnerability to a variety of man portable air defense systems (MANPADS). This is done by incorporating a computer-generated model of the C–5 with actual hardware-in-the-loop tests of several different MANPADS to determine the most likely hit locations on the aircraft. These hit points will then be used to identify critical areas affected and determine the system-level vulnerability. This work could potentially benefit the warfighter through follow-on testing with countermeasures beyond current LFT&E efforts.

Additionally, we will go into more depth on several of the innovative tests that are being incorporated into this LFT&E program. This includes the wing iron bird tests, hydro-dynamic ram—fuel spurt analysis, the armor-piercing incendiary (API) and high explosive incendiary (HEI) mini-tests, and the nitrogen suppression testing.

Wing Iron Bird test

Beyond being the largest U.S. aircraft ever to undergo LFT&E, each C–5 is a national asset. Few test assets are available and the production line no longer exists. Virtually all assets are supporting critical airlift efforts throughout the world, thus parts are in critical demand. There are numerous LFT&E ballistic issues that must be addressed, however, prior to destroying a wing asset, a series of tests will be accomplished on an Iron Bird to establish a baseline for critical LFT&E issues.

When Lockheed Martin Aero began their detailed vulnerability analysis, they found numerous data voids. Subsequently, one analytical effort and four additional test programs were planned prior to this C–5 Iron Bird test. The first mini-test program quantified the functioning characteristics of an API and HEI projectile upon impact on a very thick C–5 aluminum/aluminum honeycomb composite wing leading edge components (slats and leading edge fairing). The second mini-test program quantified threat functioning characteristics of the thick aluminum lower skin of the production C–5. This test program also determined if shots through lower skin surface will be required in the Iron Bird test series. The final two mini-test series are evaluating the effectiveness of the fire suppression system (FSS) and fuel tank ullage.

An overall LFT&E issue is: "What is the vulnerability of the C–5 to a threat induced fires?" To better understand the complex phenomena that are involved in dry bay fires, background information must first be provided that defines a dry bay and identifies the elements required for a sustained fire within this structure. This may appear to be easy until one looks at the very large dry bay area and the excessive amount of fuel that is involved. Current fire prediction and sustainment models can't handle the dry bay volume, amount of fuel, or ignition required to assess this aircraft.

In order to address ballistic issues, a surrogate wing section has been constructed (see Figure 1). The section conforms to C-5 specifications of the original aircraft, to varying degrees, depending on the shot area of the test article. Relative to the shotline; non-critical structure has been fabricated from steel; medium structure will be made of steel or aluminum with the same basic shape; high fidelity components will be C–5 components or as close to actual C–5 components as possible. Within the Iron Bird, a number of design techniques have been incorporated to ensure fast turn around with minimal loss of fidelity. Modularity combined with aircraft test fidelity was the key to Iron Bird construction.

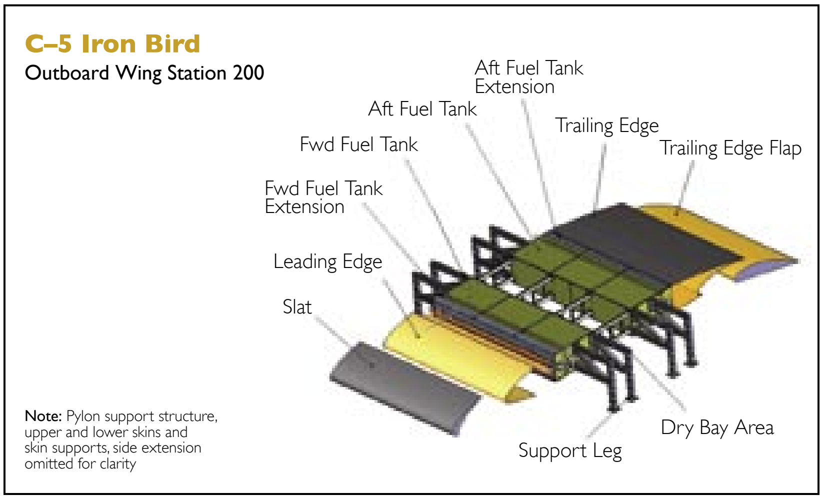


Figure 1. Replica of C-5 Iron Bird, outboard wing station 200

Hydrodynamic ram—fuel spurt analysis

Restrictions on the amount of fuel used during live fire testing force us to make adjustments to the size of the fuel tank in the area of study. These adjustments force us to ask "how does the depth of the iron bird wingbox affect the response of the entrance surface and fuel spurting due to hydrodynamic ram?" We undertook a test to understand that very thing.

In our analysis, we investigated wingbox depths of 3, 4, 5, 6, 8, 12 feet and recommended the wingbox depth for use in the live fire test. Finite element models were built for each depth using MSC/PATRAN and the analyses were performed using LS-DYNA MPP Version 970 on an SGI 3900 computer with 23mm, 14.5mm, and 12.7mm armor-piercing incendiary threats modeled with velocities of 1500fps and 2500fps.

In the study, a coupled fluid/structure interaction technique was performed where the wing box and threats meet. The threats (treated as rigid bodies) were given initial velocities and were allowed to penetrate and interact with the wingbox and fluid. Furthermore, the wingbox and fluid were allowed to interact. The volume fraction of the fluid spurting out of an entrance hole was quantified. Figure 2 shows a cut-away of the model at a snapshot in time showing the entrance hole and cavitation formation behind the projectile as it enters the fluid-filled wingbox.

The analyses showed that the 3 foot box had substantially more fuel spurt (on the order of 5 times that of the 5 foot wingbox) during the first 0.1 seconds of the event than the other wingbox depths. There were decreases (on the order of a 25 percent) as the wingbox depth was increased from 4ft to 5ft. Wingboxes deeper than 5ft showed spurt changes on the order of a few percent. Using this information and the fuel limitations of the test facility, we chose to design the Iron Bird with 5 foot wingboxes.

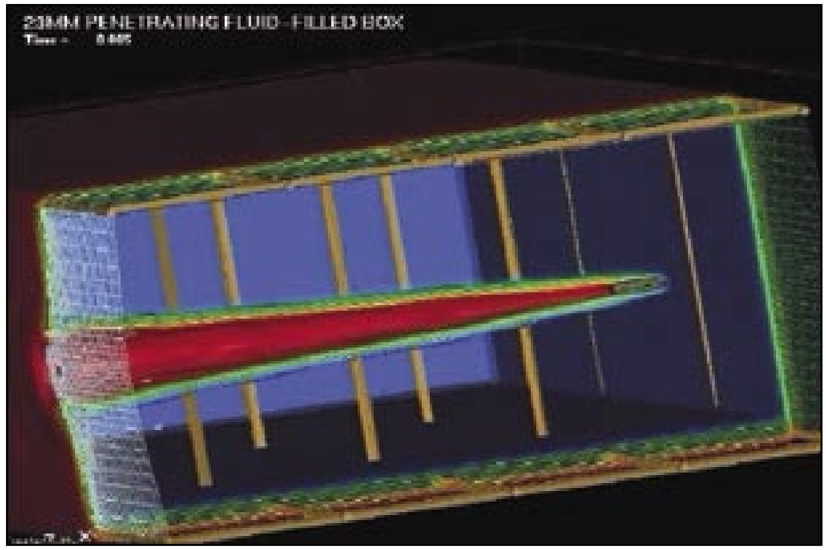


Figure 2. 23mm penetrating 4 ft. deep wingbox

API and HEI mini-test series

Because of the unusually thick aluminum skin of the C–5, little was known about the behavior of small arms threats upon impact. The use of thick honeycomb in the wing leading- and trailing-edges posed another obstacle. We designed a series of material ballistic tests to help us understand these phenomena. During the test, representative solid aluminum and honeycomb panels of varying thickness were subjected to API and HEI impacts in the 46 OG/OGM/OL–AC Aerospace Vehicle Survivability Facility (AVSF). Three things set this testing apart from previous work—

1. Material thickness
2. Data acquisition technology
3. Use of 3-D TEMA software to evaluate the API and HEI cloud

The development of high speed digital video cameras has progressed to the point where these new cameras now meet or exceed the performance of highspeed film cameras. Using Phantom V5 and V7 cameras from Photo-Sonics, Inc., and Vision Research, Inc., combined with Track Eye Motion Analysis (TEMA) software from Image Systems, 46 OG/OGM/OL–AC can record ballistic test events with sufficient speed and resolution to provide excellent qualitative and quantitative results, as shown in Figures 3 and 4.

The true innovation within this test series was the application of software developed for auto industry airbag tests to measure and quantify the incendiary cloud in 3-D as a function of time. The complete time history and spatial extent of the incendiary fireball was measured from initiation through maximum volume to decay. In addition, 3-D impact and residual projectile velocities were recorded, allowing us to fill data gaps within existing vulnerability models. This capability (cameras and TEMA software), allowed the C–5 LFT&E program to conduct 2 to 3 times as many test shots as originally planned with little impact on cost or schedule, as well as provide the analysis community a detailed recorded image and volume of the incendiary cloud as a function of time. Unexpected phenomena, such as significant impact face incendiary flash, were investigated, as well, allowing for test data to be incorporated into future fire prediction models.

Fire suppression system (FSS) tests

With non-destructive tests answers vital to vulnerability, we designed the Fire Suppression System Full-Scale Baseline testing to characterize the performance of the existing Liquid Nitrogen (LN2) fire suppression system in the wing leading edge (WLE), the wing root dry bay, and the wing dry bay. This testing will help us to

Figure 3. TEMA window showing projectile tracking and measurement

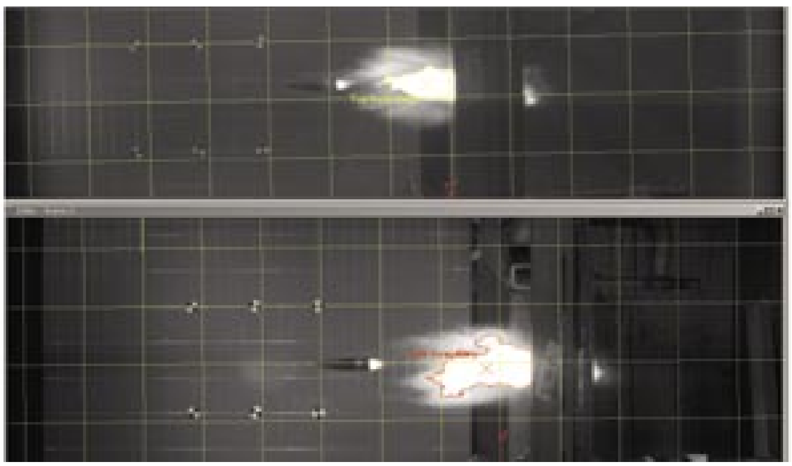


Figure 4. TEMA window showing fireball cross-section measurement

accurately recreate the current system performance in the wing Iron Bird and to assess the system's effectiveness.

Many of the live-fire tests are expected to result in fires in the WLE. To realistically assess the ability of the FSS to extinguish these fires, it is paramount that the LN2 system in the iron bird performs as accurately as the full-scale system. The data from the two dry bays will be used to better understand the capabilities of the current system and to enhance inputs used in the vulnerability analysis of the C–5 to be performed by LM Aero and by the Aeronautical System Center's Engineering Directorate (ASC/EN).

The only data requirements for this test series were to collect the oxygen concentration, as a function of time, at specified locations in the WLE, wing root dry bay and the wing dry bay. Normally this would have been accomplished by taking a gas sample via a collection bottle and having it analyzed at a laboratory but we were able to re-design the FAA flight certified system used for in-flight fuel tank ullage oxygen measurements. The analytical system employed to collect this data was custom designed for this application by Scientific Pittsburgh, and included three data acquisition units. Each box is self-contained with eight Panametrics XMO2 oxygen analyzer channels per system, totaling 24 available channels.

We were able to perform these tests on the flightline, another example of innovation within the program. This particular aircraft was being readied for Operational Test and Evaluation of the new avionics packages, truly a joint OT&E–DT&E collaborative effort. During a lull in testing, the LFT&E team set up the instrumentation to acquire Fire Suppression System data. Each channel was connected to polyurethane tubing, which terminated into a sampling probe.

Summary

A number of new initiatives are being attempted in order to address C–5 LFT&E issues. The cost cap allows for team discussions and to issue prioritization. The team must find technical and political ways to work through the LFT&E issues, providing Office of the Secretary of Defense with a solid program, yet do it in an affordable manner. There is a balance of testing and modeling that addresses LFT&E issues and present a combined package. New techniques are being investigated to obtain as much data as possible while keeping within overall cost constraints. Taking a more R&D approach, using the latest analytical codes, new instrumentation, and being able to make changes quickly are keys to the innovations taking place under C–5 LFT&E. ■

Lt Stephen N. Sacovitch received his B.S. in Chemical Engineering from Worcester Polytechnic Institute. He is currently working on his M.S. in Fire Protection Engineering for Worcester Polytechnic Institute with a planned completion of Winter 2004. He is an engineer and a test manager for the C–5 Development System Office, Mobility System Program Office, Wright-Patterson AFB, Ohio. His current duty title is C–5 LFT&E Program Manager. He may be reached at 937. 255.1043 or by e-mail at stephen.sacovitch@wpafb.af.mil.

Mr. Alex Kurtz received his B.S. in Aeronautical/Astronautical Engineering from The Ohio State University. He is a research and test engineer for the 46th Test Wing, Wright-Patterson AFB, Ohio. He has been an Aircraft Survivability Specialist for 17 years and has worked in vulnerability reduction research, Joint Live Fire Testing, Congressionally mandated Live Fire Testing and Evaluation, Transport Aircraft Survivability Program, and various international programs. He is currently the Chairman of the Aircraft and Crew Protection Committee for the Joint Aircraft Survivability Program Office (JASPO), C–5 LFT&E RTO, and the USAF JLF Deputy Test Director. He may be reached at 937.255. 6302, x250, or by e-mail at alex.kurtz@wpafb.af.mil.

Combined H–60 Helicopter Live Fire Test & Evaluation (LFT&E)

and Joint Live Fire (JLF) Programs

■ *by Mr. Frederick Marsh and Ms. Anne Hackman*

Army Black Hawk and Navy Seahawk helicopters are currently undergoing major upgrades to increase operational readiness and effectiveness. A key element of the evaluation of each system is how the upgrades affect the ballistic vulnerability. The need to reevaluate the Black Hawk and Seahawk also offers the opportunity to address outstanding ballistic vulnerability data voids for each platform. The Combined H–60 Helicopter Live Fire Test & Evaluation (LFT&E) and Joint Live Fire (JLF) Programs are the primary means by which the ballistic vulnerability evaluation of the upgraded H–60 platforms will be conducted. This article discusses the test programs developed to evaluate the ballistic vulnerability of the UH–60M Black Hawk, MH–60R, and MH–60S Seahawk, including the scope and status of the program, program coordination, test elements, and continuing efforts.

Background

The UH–60A Black Hawk and SH–60B Seahawk were developed in the 1980s by the Sikorsky Aircraft Company to serve as the front-line utility helicopters for the U.S. Army and U.S. Navy, respectively. Variants of each platform were also developed to address special mission needs, such as medical evacuation and mine-hunting. With each of the H–60 platforms reaching a service life of 25 years, the aging fleet has begun to demonstrate decreases in reliability and operational readiness. To combat this decline, the Army UH–60 and Navy SH–60 (now designated MH–60) platforms, shown in Figures 1 and 2, are undergoing significant upgrades. The Army's UH–60M Black Hawk and the Navy's MH–60S and MH–60R Seahawk Recapitalization/Upgrade Programs are major acquisition programs that will include evaluation of the platforms' ballistic vulnerability testing under Live Fire Test & Evaluation (LFT&E) and Joint Live Fire (JLF) programs.

The LFT&E program was conceived in 1986 to address critical vulnerability and lethality issues for armored vehicles, as regulated by the Live Fire Law provisions in Title 10 of the United States 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. In accordance with the Live Fire Law, the UH–60M program is a "covered" product improvement and must undergo a LFT&E program prior to the full-rate production (FRP) decision. The Live Fire Law also mandates full-up system-level (FUSL) testing on a production-representative asset unless such testing would be "unreasonably expensive and impractical." Accordingly, the Office of the Secretary of Defense (OSD) granted the UH–60M program a waiver from FUSL Live Fire testing in March 2000. In lieu of FUSL Live Fire testing, an alternate LFT&E program was developed which will use a combination of component-level testing, subsystem-level testing on partial H–60 assets, system-level testing on a YCH–60S ground test vehicle (GTV), prior ballistic test data, modeling and simulation (M&S), and qualitative analyses to evaluate the aircraft's vulnerability.

The JLF program is similar in mission to the LFT&E program, but is a means to evaluate the survivability of fielded systems rather than new or upgraded systems. The UH–60A Black Hawk underwent an extensive JLF test program from 1986 to 1994 that addressed many critical vulnerability issues. However, due to limited resources, hardware, and funding, a subset of vulnerability issues could not be fully addressed with testing. This resulted in some outstanding data voids and recommendations for future testing. Because the platform upgrades necessitate ballistic testing under LFT&E, a concurrent JLF test program to address outstanding data voids from the UH–60A JLF program is a logical occurrence.

During development of the UH–60M and MH–60S/R LFT&E and JLF programs, a recommendation to combine the Army and Navy test efforts was presented by OSD/Director of Operational Test and Evaluation (DOT&E), based on

Figure 1. U.S. Army's UH-60 Black Hawk

Figure 2. U.S. Navy's MH-60 Seahawk

known similarities in the platforms. An extensive review of the UH–60M, MH–60S, and MH–60R platforms revealed a great deal of commonality among the platforms. The flight controls, main and tail rotor drive trains, main fuel subsystems, cockpit, engines, and vertical pylon structure are similar in the UH–60M and one or both of the MH–60 platforms. In conjunction with the platform similarities, the compatible milestone schedules for the Recapitalization/ Upgrade Programs offered the Army and Navy an opportunity to combine resources in addressing the ballistic vulnerability of the H–60 platforms. As part of the Combined Army/Navy H–60 LFT and JLF Test Programs, the Army and Navy will share data, test responsibilities, and assets to save the respective program offices considerable cost and time in addressing the ballistic vulnerability of the H–60 platforms.

Program scope

The Combined H–60 LFT and JLF Test Programs have been designed to address vulnerability data voids for a number of common H–60 subsystems. Testing that has been completed as part of the Combined H–60 Program includes static and dynamic main rotor flight controls, dynamic main rotor drive train, and static and dynamic main fuel subsystem testing. Upcoming testing includes the tail rotor subsystem, vertical pylon structure, T700–701C engines, and engine fire suppression subsystems. The Army and Navy are also each conducting separate ballistic test efforts to address platform-specific H–60 subsystems. One example is main rotor blade testing. The Army and Navy will conduct testing of their main rotor blades, but the data will be Service-specific. Additional subsystems to be tested separately include the UH–60M On-Board Oxygen Generating System (OBOGS) and crashworthy external fuel sub-system, the MH–60R main fuel subsystem, and MH–60R/S tail pylon fold point. The program and ballistic test schedule is shown in Figure 3.

Program coordination

At the inception of the Combined H–60 LFT and JLF Test Programs, the Army and Navy established the responsibilities of each service by developing and approving a Combined Army/Navy H–60 Memorandum of Agreement (MOA). The MOA, signed by the Army and Navy H–60 program offices, outlines all aspects of conducting the Combined H–60 Program, including program planning, testing responsibilities, repair efforts, and sharing of test assets.

Program planning

In accordance with the Combined H–60 MOA, the service conducting the ballistic test series is responsible for the planning documentation and reporting. However, all planning for Combined H–60 Program tests must be coordinated and approved by both the Army and Navy H–60 representatives. Although having two approval agencies results in additional time required to plan testing, the Army and Navy have cooperated successfully in ensuring test planning proceeds efficiently and addresses the needs of both services.

Test responsibilities

The U.S. Army Research Laboratory (ARL) at Aberdeen Proving Ground, Maryland, and the U.S. Naval Air Warfare Center Weapons Division (NAWCWD) at China Lake, California, are the test agencies for the Army and Navy, respectively. Both test facilities are fully equipped to instrument, conduct, and record a broad spectrum of static, loaded, and dynamic ballistic tests. Multiple test sites at each facility also allow the setup of one series during the conduct of another or provide for multiple test series to occur concurrently.

As part of the Combined H–60 Program, ARL has conducted ballistic tests on the main rotor flight controls (static-loaded), the main fuel subsystem (static and dynamic), the tail rotor subsystem (static and dynamic), and is currently preparing for the vertical pylon structure test series. After the vertical pylon structure test series is complete, ARL will conduct the static T700 engine LFT.

The NAWCWD has conducted ballistic tests on the main rotor flight control and main rotor drive train subsystems (dynamic), as well as the Navy-specific fuel subsystem and main rotor blades (dynamic). The NAWCWD is currently preparing for T700 engine (dynamic) and engine fire suppression subsystem testing.

The sequence of engine testing demonstrates the level of coordination required between ARL and NAWCWD since the data from the Army-conducted engine testing is necessary to support the Navy-conducted engine testing. Coordination of data between the Army and Navy has been crucial to the success of the Combined Program (see Figure 3).

Repair efforts

In addition to the ballistic vulnerability of the H–60 platforms, repairability of the platforms following a ballistic incident is being considered carefully as part of the Combined H–60 Program. Like ARL and NAWCWD, the U.S. Army Aviation Logistics School (USAALS) at Fort Eustis, Virginia, and the Navy logistics personnel from the Logistics division of the Program Office at Cherry Point, North Carolina, have coordinated Combined H–60 Program repair efforts to most efficiently obtain and document H–60 repair data. Throughout the Combined H–60 Program, USAALS has been an active and valuable participant. Not only is USAALS responsible for assessing battle damage, but the organization has also played a key role in asset preparation for the Army LFT and JLF testing. Soldiers from USAALS have taken the opportunity to obtain "hands-on" experience in building and repairing H–60 assets to be used for testing at minimum cost and time commitment to the Combined Program.

Test assets

Because ballistic testing of a production-representative asset (UH–60M and MH–60R/S) was deemed impractical, the UH–60M program was granted a waiver from full-up system-level (FUSL) LFT&E by the DOT&E. Therefore, all LFT and JLF testing is being conducted on high-fidelity, but partial assets. The Navy supplied a fully operable YCH–60S helicopter asset that is currently being used as the primary

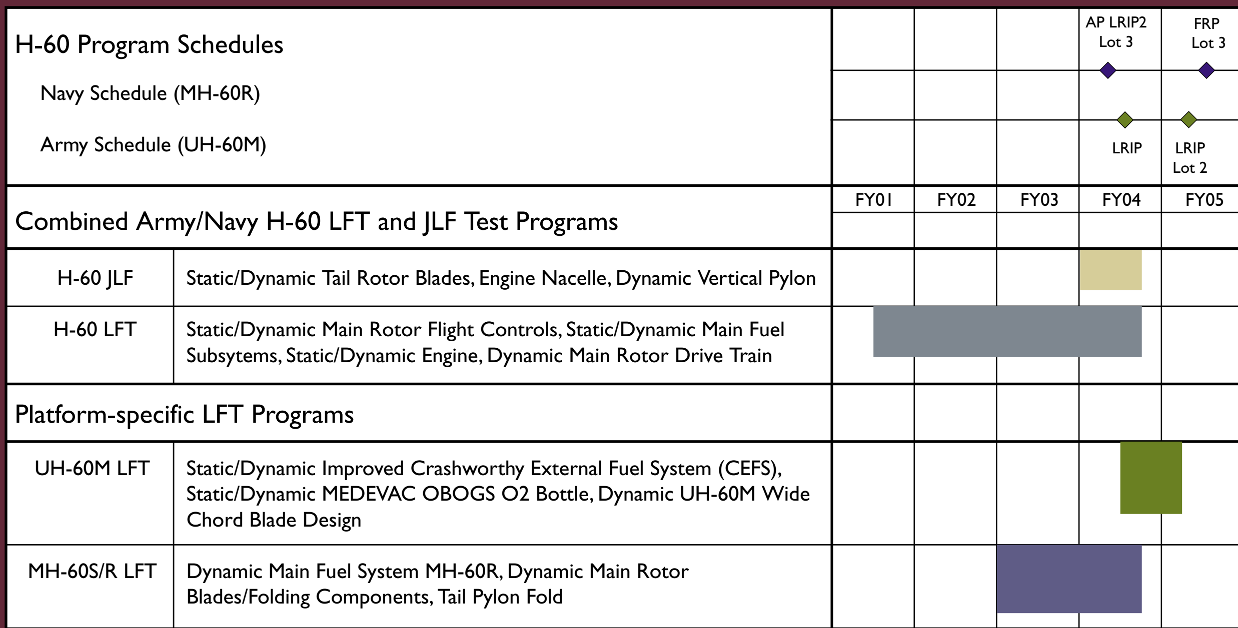


Figure 3. Army and Navy UH-60M and MH-60S/MH-60R LFT and JLF est schedule

ground test vehicle (GTV) for most of the LFTs. Partial H–60 fuselage test assets (UH–60 and SH–60) have been built from and/or populated with components from several crash-damaged H–60 assets. Test stands are also viable assets for the Combined H–60 Program and are used for component-level testing.

Several test assets for the Combined H–60 Program are shared between the Army and Navy. By the end of the program, the YCH–60S GTV will have been shipped three times between Aberdeen Proving Ground and China Lake. Selected partial fuselages were developed jointly or developed and shipped to the Army or Navy for use as needed.

Although the assets are not fully production-representative, each test series has been designed to achieve the highest level of fidelity possible. For example, the static component-level testing for the main rotor flight controls included several ballistic events versus the pitch control rods. A main rotor head test asset was created using a partial main rotor head and spare parts as shown in Figure 4.

A hydraulic actuator applied static compressive and tension loads to the pitch control links during the LFT. Cyclic tensile and compressive loads were also applied following the ballistic event to simulate the loads the damaged pitch control link would experience during flight. The additional fidelity had little to no cost or time impact on the Combined H–60 Program.

Additional realism incorporated into the H–60 testing includes preventative shutdown procedures—to preserve the Combined Program's YCH–60S GTV—based on expected pilot response to vibration levels in the cockpit as specified in the H–60 technical manuals. Further, the test stand for the GTV (as shown in Figure 5) is a "floating" stand that was designed to simulate hover conditions more closely than a rigid stand. By monitoring the pressures in air-bags at four locations on the test stand, if the GTV leaves the hover condition following the ballistic impact, the moment at which the system may lose altitude in a real-life condition is more clearly defined.

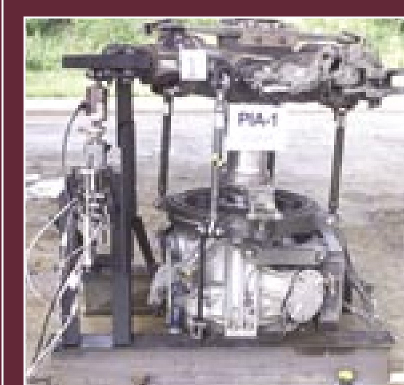


Figure 4. Static main rotor flight controls LFT stand

Execution of the Combined H–60 Program has demonstrated that a great deal of fidelity is achievable without expending significant time or money.

Continuing efforts

In conjunction with the upcoming LFT and JLF testing, additional vulnerability issues continue to be assessed to improve the ballistic survivability of the Army and Navy H–60 platforms.

The repairability of the H–60 platforms has already experienced improvement based on the Combined H–60 Program. Components of a small and lightweight fuel cell repair kit, developed by USAALS, were used extensively during H–60 main fuel subsystem LFT to repair the fuel bladders between tests. The fuel cell repair kit has now undergone qualification testing and is approved for use in the field to expedite ballistically induced repairs. The goal of USAALS is to develop similar small and lightweight repair kits for the remain-

Figure 5. YCH–60S GTV On "Floating" Test Stand

ing UH–60M subsystems, many of which will be applicable to both the Army and Navy H–60 platforms.

Finally, the run-dry capability of the Improved Durability Gearbox (IDGB) was qualified by similarity with the main gearbox it replaced, but was never ballistically tested. A proposal to evaluate the ballistic tolerance and run-dry capability of the IDGB will be submitted for the inclusion into the FY05 JLF Program.

The H–60 platforms were some of the first rotorcraft designed with ballistic survivability in mind, and the platforms have a long and successful history of service. The Combined Army/Navy H–60 LFT and JLF Test Programs will assist in continuing this tradition with the new generation of H–60 platforms. ■

Figure 6. HH-60 Blackhawk

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Ms. Anne Hackman is a Mechanical Engineer at the SURVICE Engineering Company in Belcamp, Maryland. She has provided LFT&E support to the UH–60M system government evaluator since the development phase of the Combined Army/Navy H–60 LFT&E and JLF Test Programs. She also completed a study regarding damage mechanisms versus armored targets and presented the findings at the 2000 Nation Live Fire Test and Evaluation (LFT&E) Conference. Her main body of experience is in ballistic vulnerability analysis, for which she has supported the Joint Strike Fighter (JSF), Expeditionary Fighting Vehicle (EFV), Affordable Apache Rotor Program (AARP), and assessment of foreign systems for the Joint Technical Coordinating Group for Munitions Effectiveness (JTCG/ME). She received a Bachelor of Science in Mechanical Engineering from the University of Maryland at Baltimore County in 1998. Ms. Hackman may be contacted by e-mail at anne@survice.com or by telephone at 410.273.7722.

CH–47F Helicopter Live Fire Test & Evaluation Program

■ *by Mr. Frederick Marsh, Mr. Bruce Wheeler, and Ms. Kristin Rose*

The CH–47F Improved Cargo Helicopter (ICH) is currently being developed by Boeing to replace the aging fleet of Army CH–47D Chinook helicopters. As part of this effort (and in compliance with the 1986 Live Fire Law), the CH–47F Live Fire Test and Evaluation (LFT&E) Program was initiated in 1999 to evaluate the vulnerability of the aircraft through component- and subsystem-level testing and analysis as well as applicable modeling and simulation (M&S). This article provides an overview of the CH–47F platform improvements, test requirements in accordance with the Live Fire Law, the scope of the LFT&E program, and contributing organizations and their responsibilities.

Vehicle background

Development of the original CH–47 Chinook began in 1956 as a medium-lift cargo helicopter. In the nearly five decades since its emergence, the aircraft has seen extensive use in many major military operations, including the Vietnam War, Operation Desert Storm, peacekeeping operations in Bosnia, Operation Enduring Freedom in Afghanistan, and Operation Iraqi Freedom. Although this twin-rotor, twin-turbine engine helicopter was initially designed for transporting weapons, cargo, and troops within the combat area, improvements over the years have enhanced its mission capabilities and lengthened its service life. Today, in addition to performing its original transport missions, the CH–47 is also used for rescue, aeromedical transport, parachuting, aircraft recovery, and special operations missions.

The CH–47D, which was developed in 1976, is a modernized version of earlier CH–47 helicopters. Currently used by the U.S. Army, the aircraft has a crew of four, a 30-foot-long cargo compartment with straight-in rear loading, and accommodations for 24 medical litters and two attendants, or 31 combat equipped troops. It also has three cargo hooks, which are used to transport external loads. The CH–47F (shown in Figure 1) is a service-life extension program (SLEP) for existing CH–47D cargo helicopter airframes. The upgrades on the CH–47F include an airframe life extension, a tuned airframe, and an advanced cockpit with digital data bus. Also included, but under a separate fleet-wide program, is an upgrade to the T55–GA–714A engine.

Live fire law requirements

The CH–47F program is considered a "covered" product improvement under the Live Fire Law provisions of Title 10, United States Code, Section 2366, which requires the realistic vulnerability testing of full-up, combat configured aircraft. This law was conceived in 1986 to address the survivability and lethality of armored vehicles and was updated in 1987 to include all major conventional land, air, and sea systems, as well as all major munitions and missile programs. In accordance with the law, select new systems and major system upgrades shall undergo Live Fire Testing (LFT) prior to full-rate production (FRP); however, the legislation also authorizes the Office of the Secretary of Defense (OSD) to grant a waiver from full-up testing if such testing is considered to be "unreasonably expensive and impractical."

Accordingly, in March of 1998, OSD certified that a full-up LFT program for the CH–47F would be unreasonably expensive and impractical for a few particular upgrades and waived the requirement for full-up system level testing. Instead, an alternate live fire program was developed with component-level testing, a CH–47D ground test vehicle (GTV) for system-level tests, previous live fire testing, and M&S analyses used to evaluate the aircraft's vulnerability.

Program objectives, scope, and approach

The primary objective of the CH–47F LFT&E Program is to investigate the possibility that a single hit by a ballistic threat will cause a catastrophic fire or explosion, crash, forced landing, or a mission abort. Specific emphasis was placed on evaluating user casualties, the causation of "cheap kills," and whether CH–47F changes result in increased crew casualties and system vulnerability compared to the CH–47D. In addition, the program offered a unique opportunity to incorporate vulnerability reduction measures into the aircraft's design.

A combined approach using M&S, analysis, and experimentation and testing (both nondestructive and destructive) was used to obtain the required data to answer the critical LFT&E issues. M&S was used whenever possible to scope and focus the tests to be performed, to aid in the selection of components and shotlines, and to evaluate conditions and threats not specifically tested.

A detailed data search conducted early in the program showed that only a limited amount of component vulnerability test data existed for the CH–47. In addition, these tests focused primarily on small arms threats and did not address other threats likely to be encountered on

Figure 1. U.S. Army CH-47F Chinook

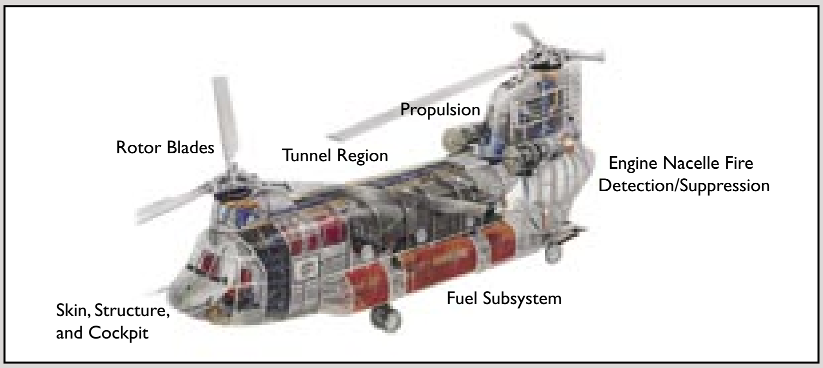

Figure 2. Systems tested under the LFT&E program

Figure 3. CH-47F test pad

today's battlefield. Also, the bulk of the data were derived from tests performed on similar components from other types of aircraft. There were no test or vulnerability data for any CH–47F-specific components.

Although a significant amount of Vietnam combat data exists for the CH–47A/C aircraft (approximately 2,000 incidents), several factors limited its usefulness in answering the critical LFT&E issues for the CH–47D and CH–47F. First, the CH–47D modifications such as composite (versus metal) rotor blades, new transmission designs, improved hydraulic and flight control systems, composite material oil sumps, and other changes made much of the Vietnam combat damage data for the CH–47A/B/C models inapplicable. In addition, the threat data were limited to only a small sample of the anticipated threats, and the combat data records often lacked sufficient detail for use in an accurate analysis of the aircraft.

Six critical areas were tested under the CH–47F program (see Figure 2). These tests, which are discussed in the subsections that follow, include the—

1. Skin, structure, and cockpit
2. Rotor blades
3. Tunnel region
4. Propulsion
5. Engine fire suppression
6. Fuel subsystem

Some tests were conducted on a damaged CH–47D helicopter with few flight hours that was restored to functional condition. During these tests, the helicopter was secured to a test pad while operating in ground effect hover (see Figure 3). For other tests, a partial CH–47 fuselage was used or individual components were evaluated outside of the helicopter.

1. **Skin, structure, and cockpit**—This phase of the program was conducted to determine the vulnerability of the CH–47F crew and passengers by performing tests against skin panels, avionics components, and a representative cockpit. Specific issues related to the effect of the CH–47F airframe modifications on the fuzing of high-explosive (HE) projectiles, and jacket stripping of armor-piercing incendiary (API) projectiles were addressed. The degree of protection provided to the crew by avionics. and the contribution of debris from impacted avionics, were also evaluated. Figure 4 illustrates a representative cockpit

and the setup for component-level testing.

2. **Rotor blades**—Static and quasi-static rotor blade testing was conducted on production representative blades. The static (no loading) tests were performed using sections of the rotor blade to characterize the type and extent of physical damage, while the quasi-static (statically loaded) tests were performed using longer blade sections to quantify the effects of the damage on the blade's structural and dynamic properties. The damaged sections of the rotor blades were tested to determine changes in structural strength and stiffness and to evaluate remaining fatigue life.

3. **Tunnel region**—This phase of testing evaluated the vulnerability of the CH–47F hydraulic subsystems, mechanical and hydraulic flight controls and components of the rotor drive train located in the tunnel (i.e., top fuselage) area of the aircraft.

4. **Propulsion**—Testing during this phase evaluated the vulnerability of the T55–GA–714A engine to failure or loss of power following a ballistic impact. The tests also evaluated the collateral damage from an uncontained failure of the T55–GA–714A engine and the operational significance of this damage to the helicopter. The effectiveness of the helicopter to operate on one engine following a ballistic hit was also evaluated.

5. **Engine fire suppression**—Testing during this phase of the program evaluated the likelihood of hot surface ignition of leaked fuel and the effectiveness of the fire detection and suppression system in preventing a catastrophic fire. Projectile functioning and fuzing and fuel leakage rates and durations in the CH–47 engine nacelle were examined as part of the test process.

6. **Fuel subsystem**

   a. **Fuel plumbing**—Testing of the CH–47F fuel lines and associated fuel distribution components was performed to determine their vulnerability to leakage that could result in loss of engine power and/or fire. Other issues included vulnerability to dry bay fires and the effectiveness of the fuel lines to self-seal following a ballistic impact.

   b. **Fuel tanks**—Testing of the CH–47F fuel tanks examined the vulnerability of the fuel subsystem to ullage explosions and dry bay fires. The effects of hydrodynamic ram caused by ballistic impacts to the fuel cells and the fuel cell's ability to self-seal were also evaluated. Figure 5 illustrates the subsystem-level fuel tank test setup.

Figure 4. CH-47F component-level cockpit test setup

Figure 5. CH-47F fuel tank test

In addition, a collaboration of the CH–47F LFT&E test team and the CH–47F Program Management Office (PMO) led to an Auxiliary Power Unit (APU) shield for the aircraft. In response to the grounding of a large number of U.S. Army CH–47D helicopters due to uncontained APU compressor failures, a research and development task was undertaken to identify and qualify an effective barrier material to protect personnel and critical aircraft subsystems from ejected APU debris.

Program responsibilities

To conduct the CH–47F LFT Program, a LFT&E Integrated Product Team (IPT) was established in June 1997. The IPT consisted of the CH–47F Program Manager (PM)–Cargo Helicopter, the OSD/Director of Operational Test and Evaluation (DOT&E), Headquarters, Department of the Army (HQDA)—Office of Deputy Under Secretary of the Army (Operations Research) (DUSA[OR]), the U.S. Army Test and Evaluation Command (ATEC), the U.S. Army Evaluation Center (AEC), the Survivability/Lethality Analysis Directorate (SLAD) of the U.S. Army Research Laboratory (ARL), the Director of Combat Development (DCD) from Fort Rucker, the U.S. Army Aviation Logistics School (USAALS) from Fort Eustis, and the Boeing Helicopter Company.

The AEC representative serves as the chair of the LFT&E IPT and leads in the organization and development of the LFT&E strategy. The AEC is responsible for providing an independent evaluation of the CH–47F. In developing the evaluation, the AEC representative has program involvement by participating in test events and serving as a primary member of the Damage Assessment Team.

The CH–47F PMO representative is an active member of the LFT&E IPT and serves as the lead for development and staffing of the Test and Evaluation Master Plan (TEMP). The PMO provided funding for the LFT&E preparation and execution, provided the CH–47D test asset, and supplied the contractor support as required. In addition, the PMO ensured that any user-directed design fixes identified during testing were within the program constraints, were developed, and were implemented.

ARL/SLAD served as the focal point for the vulnerability analysis of the CH–47F and worked together with ATEC/AEC in identifying critical vulnerability issues and developing test design and data requirements. SLAD per-formed and documented (through DTPs & FTRs) the live fire tests; provided M&S support, pretest predictions, test facilities, and the previously mentioned partial CH–47 fuselage; conducted the analysis of the test results; and chaired the LFT&E Damage Assessment Team.

USAALS provided general aircraft maintenance and logistics support for the live fire program. In addition to regular maintenance, the school also provided support for Battle Damage Assessment and Repair (BDAR) and repairs to the aircraft beyond BDAR. Following each test, any damage sustained by the test article was evaluated for repair using BDAR techniques to ready the test article for the next test. USAALS also provided students and instructors to help prepare the test targets. Sections of the fuselage were built up for fuel testing as part of training exercises.

Summary

In conclusion, the CH–47F enhancement programs will allow the battle-proven CH–47 to remain a viable military asset for Army XXI forces. Data and lessons learned from the CH–47F LFT&E will identify critical component and subsystem ballistic vulnerabilities and will aid in developing solutions to improving survivability on future bat-tlefields.

For more information on the CH–47F LFT&E program, contact Mr. Frederick Marsh of ARL/SLAD. He may be reached via e-mail at marsh@arl.army.mil. ■

Mr. Frederick Marsh is a General Engineer for the U.S. Army Research Laboratory's (USARL) Survivability/Lethality Analysis Directorate (SLAD), Engineering, Design, Conduct, and Analysis Branch (EDCAB), located at the Aberdeen Proving Ground in Aberdeen, Maryland. After graduating from the Loyola College of Baltimore in 1987 with a Bachelor of Science Degree in General Engineering, Fred came to work for the U.S. Army Ballistic Research Laboratory (later absorbed into ARL) in 1990. Mr. Marsh serves ARL as a ballistic vulnerability test engineer and analyst and currently holds the position of SLAD's UH–60M Black Hawk System Leader. In September of 2003, Mr. Marsh was also appointed as SLAD Team Leader for the EDCAB's Experimental Facility Team. Mr. Marsh may be reached by e-mail at marsh@arl.army.mil or by telephone at 410.278.9271.

Mr. Bruce Wheeler is a survivability analyst for the SURVICE Engineering Company in Belcamp, MD, with over 16 years of experience in the field of aircraft vulnerability. His versatile experience and knowledge range from system- and component-level testing to analytical assessment of military systems. Mr. Wheeler has been involved with the CH–47F ICH IPT and has assisted in the planning and development of the CH–47F LFT&E Test Strategy. Mr. Wheeler may be contacted by e-mail at bruce@survice.com or by telephone at 410.273.7722.

Ms. Kristin Rose is a chemical engineer at the SURVICE Engineering Company in Belcamp, Maryland, and is currently supporting the Army Evaluation Center in non-ballistic and ballistic survivability analysis. In addition to working the CH–47F Chinook program, Kristin is involved with other programs, including Stryker and Aerial Common Sensor. She holds a Bachelor's degree in Chemical Engineering from the University of Delaware, where she is currently working on a Master's degree in Material Science and Engineering. Ms. Rose may be reached by e-mail at kristin@survice.com or by telephone at 410.273.7722.

United States Marine Corp H–1 Upgrades

Survivability

by Ms. Anastasia D. Goldsmith

In an effort to revitalize an aging fleet of Cobras and Hueys, the U.S. Marine Corps is introducing new upgrades to create the high performance AH–1Z and UH–1Y with an Initial Operation Capability (IOC) in 2006. Approximately 180 AH–1W Super Cobras and 100 UH–1N Hueys will begin converting to the upgraded configurations starting in FY 2006. The new features incorporated in the upgraded aircraft make these aircraft extremely important to the Marine Corps future capabilities. Upgrading the drive systems, as well as structural changes, will provide improvement in aircraft capabilities. Also, not only are parts replacements accommodated between model-to-model in the upgraded versions, but between the attack and utility versions of the H–1 due to the 84 percent commonality of components between the separate systems.

Upgrades common to both aircraft include run-dry gearboxes (90 degree tail rotor and 42 degree intermediate), combining gearbox, main transmission, main rotor, drive and controls, tail rotor drive, four blade composite tail rotor blades, four blade composite main rotor blades, an improved tail boom, and an infrared (IR) suppressor. In addition, similar fire suppression systems are included in both aircraft. Uniquely, the AH–1Z has an integrated cockpit and a weapons pylon upgrade. Also, the UH–1Y uses the T–700–GE–401C engines to replace the existing engines and also has an extended fuselage.

The new improved AH–1Z and UH–1Y helicopters have many enhanced survivability features over their predecessors. These enhancements include both arenas of survivability in vulnerability and susceptibility reduction. These improvements include IR suppressors, integrated ASE suite for radar, missile, and laser warning, and increased countermeasure dispensing for susceptibility reduction. Vulnerability advancements include increased ballistic tolerance of components, increased redundancy, nitrogen ullage inerting, dry bay fire protection, crashworthy, self-sealing fuel cells, and hydraulic isolation valves. Baseline configuration also includes run-dry gearboxes, and large diameter control tubes.

H–1 Upgrades Performance

COBRA	AH–1W	AH–1Z	*Improvement*
Max Gross Weight (lbs)	14,750	18,500	25%
Max Internal Fuel (lbs)	2,100	2,858	36%
HOGE Gross Weight/hot (lbs)	3,986	16,900	324%
Long Range Cruise Speed @ 3,000ft (kts)	131	134	2%
Mission Radius with Payload (nm)	50	125	150%
Maneuverability, g's	+0.5 to +2.4	+0.5 to +2.8	
HUEY	**UH–1N**	**UH–1Y**	***Improvement***
Max Gross Weight (lbs)	10,500	18,500	76%
Max Internal Fuel (lbs)	1,360	2,584	90%
HOGE Gross Weight/hot (lbs)	3,532	17,236	388%
Long Range Cruise Speed @ 3,000ft 33°C	107	135	26%
Mission Radius with Payload	50	130	160%
Maneuverability, g's	+0.5 to +2.27	+0.5 to +2.8	

Source: Bell Helicopter

Figure 1. H–1 upgrades features

Although Title 10 of the U.S. Code Section 2366 establishes weapon systems survivability and lethality testing requirements before full-scale production can take place, the UH–1Y has secured a waiver as the AH–1Z full-up test will fulfill the requirements for the systems due to the 84 percent commonality between platforms. The UH–1Y waiver was approved by the Office of the Secretary of Defense (OSD) prior to the program Milestone II decision on October of 1996. A nearly full-up UH–1Y will be tested as part of the waiver agreement.

Live Fire Testing and Evaluation (LFT&E) of the H–1 Upgrades program began in 1998 and will culminate in a final summary report upon completion of testing in 2005. The test program includes 21 test events ranging from small component level shots to the testing of a full-up running AH–1Z. With 76 percent of the live fire events completed, only five tests remain, the AH–1Z wing hydraulic ram/fuel inges-tion, AH–1Z wing mounted munitions, AH–1Z fuselage structural article, UH–1Y nearly full-up and AH–1Z full-up tests. All of the remaining tests will be conducted at the Weapons Survivability Laboratory located at the Naval Air Warfare Center—Weapons Division in China Lake, California.

Live fire testing has progressed fairly well. One of many successes was with the main rotor pitch link component test. The main rotor pitch link transmits inputs from the swashplate assembly to the main rotor hub, changing the pitch of the blades. The ballistic test was conducted to determine the strength characteristics of component design. The projectile was aimed to hit the pitch link and create a single or double aperture wound (see Figure 2). The component was statically loaded in the testing apparatus for the ballistic portion of the test, then post damaged fatigued in the same set-up. The component was able to tolerate a much larger caliber threat than required and LFT&E demonstrated the robustness of the design.

The coming months will be extremely busy for the H–1 Upgrades LFT&E program as we ramp up towards the most complicated test events to date. These tests will require substantial effort in planning and preparation, as well as reporting, for the Milestone III decision scheduled for August 2005. ■

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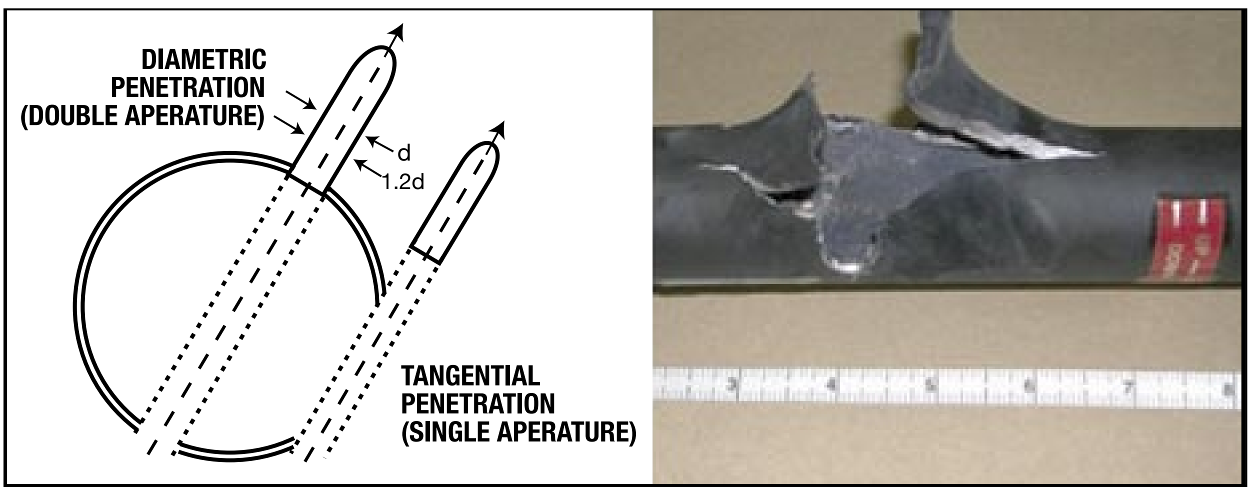
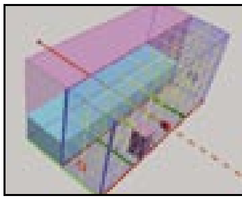


Figure 2. Shot pitch link



The Fire Prediction Model

Enhancing Analyses of Survivability and Vulnerability

■ *by Ms. Kristin Rose*

In the summer 2002 issue of *Aircraft Survivability*, an article was published on the features of the Dry Bay Fire Model (DBFM), developed by Andy Pascal of Enthalpy Corporation. As the article explained, DBFM is designed to simulate events occurring during the penetration phase of a ballistic threat, through a vehicle's dry bay and into a flammable liquid-filled container, such as fuel tanks, fuel lines, and hydraulic lines. Since the DBFM article was published, many enhancements to the model have been developed, including an integration of the DBFM with the Army's Ground Vehicle Fire Model (GVFM), also developed by the Enthalpy Corporation. The newly integrated model is now known as the Fire Prediction Model (FPM). FPM is designed to simulate ballistically induced ignition, initiation, and sustainment of fires, in both air and ground-mobile combat systems. The most current version of FPM is version 3.2.1, which includes an enhanced flow field, fire suppression, user-defined liquids, the WINFIRE 3.2.1 graphical user interface (GUI) with a geometry visualization tool, and two-dimensional and three-dimensional post-processing visualization tools. Some applications for FPM include planning and analysis support of live fire tests, vulnerability estimates, and system design. This article presents an update of new features in FPM, how FPM is being used within the aircraft survivability community (particularly in Live Fire programs), and FPM developmental plans.

Features of FPM 3.2.1

The current FPM has incorporated improvements to features that were present in the DBFM and previous versions of FPM, as well as new features, that further enhance the capability of the model. These improvements and new features are summarized in the subsections that follow.

Improved features

One improved feature is the number of clutter and barrier items that can be modeled. Clutter items are used to define nonflammable items such as electronic boxes and miscellaneous structures. Barrier items are used to define structures and components that will impede the flow and spread of fluid pooling at the bottom of the dry bay. The old DBFM allowed the user to define up to 10 clutter and 10 barrier items in order to model the dry bay, while the new FPM version 3.2.1 has the improved capability to model up to 100 clutter and 50 barrier items in the dry bay configuration. This upgrade allows the user to create more realistic dry bay configurations.

Another improvement is the WINFIRE GUI, developed by Booz Allen Hamilton, to provide an easy-to-use interface, to control all aspects of FPM including input settings, model execution, and result presentation for viewing. A snapshot of the WINFIRE GUI, which is written in Java and is supported on Windows, Linux, Solaris, and IRIX operating systems, is shown in Figure 1. The GUI was available with the previous version of FPM, but further improvements have been made for FPM version 3.2.1. The advantages of the WINFIRE GUI are summarized as follows—

- Model settings are retained for successive model runs, making it easy to change individual settings and execute subsequent FPM runs.
- Geometry viewing utility provides for viewing the dry bay, fuel tank, and other components in three dimensions prior to the shot.
- Embedded text editor allows viewing and printing of results.
- The SURVICE Engineering Company's FPM 2-D and 3-D graphics programs are integrated for viewing results.
- Model inputs are checked for errors.

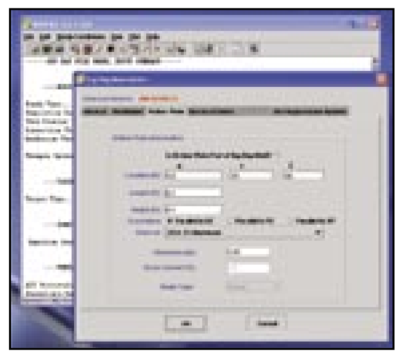


Figure 1. WINFIRE GUI (Windows version shown)

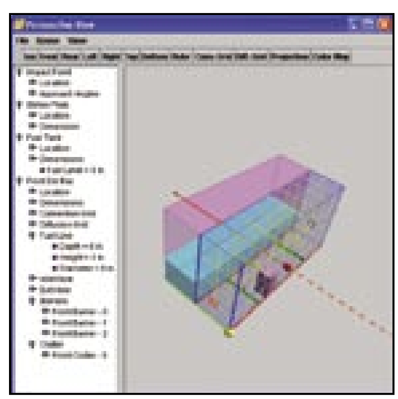


Figure 2. WINFIRE GUI geometric viewing utility

- Quick summary window shows all model inputs settings.

- The user defines output filenames.

- Configuration settings can be saved to files for future sessions.

- Model is simply installed with Wizard installation program.

As mentioned, the GUI has a utility that allows the user to visualize the dry bay configuration prior to the model's execution. The tool gives the user the ability to view grids, rotate, and highlight components. Figure 2 shows an example of the GUI's geometric viewing utility.
In addition, SURVICE has worked closely with the Enthalpy Corporation to develop various post-processing tools that can assist the analyst in understanding the model results and conveying the results to developers and decision makers. Developed under a SURVICE Independent Research and Development (IR&D) program, the FPM 2-D creates a visual representation of the fire and its flow characteristics.. The 2-D tool provides discrete section cuts through the dry bay, allowing the user to step through time at specific locations within the bay and view various outputs, such as oxygen vapor density, fuel vapor density, and temperature. The 2-D tool was available in the previous version of FPM, but improvements were made to the temperature scales. Specifically, adjustments were made to the colors and transparencies associated with the temperatures, to provide a more realistic representation of the fire seen in the 2-D output. Figure 3 shows a screen of the improved FPM 2-D output utility.

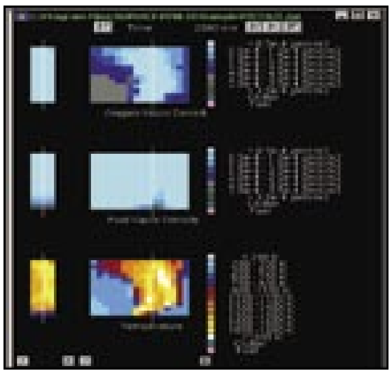


Figure 3. FPM 3.2.1 2-D post-processing visualization output

New features

In addition to the improved features of the FPM, the current version includes several new features. One is the 3-D visualization tool, which significantly enhances visualization of the FPM output. SURVICE developed the tool under contract to the Joint Aircraft Survivability Program Office (JASPO) as a new post-processor in the FPM 3.2.1. This 3-D tool uses the open-source Visualization Tool Kit (VTK) graphics engine. VTK incorporates a "ray-casting" technique that produces a solid representation of the cells and an interpolation mechanism, which provides a smoother and more realistic transition between grid cells. The user can rotate, pan, and zoom on the 3-D image produced. Selected time steps and animation of the model output can also be viewed. Figure 4 shows some images of the FPM 3-D output.

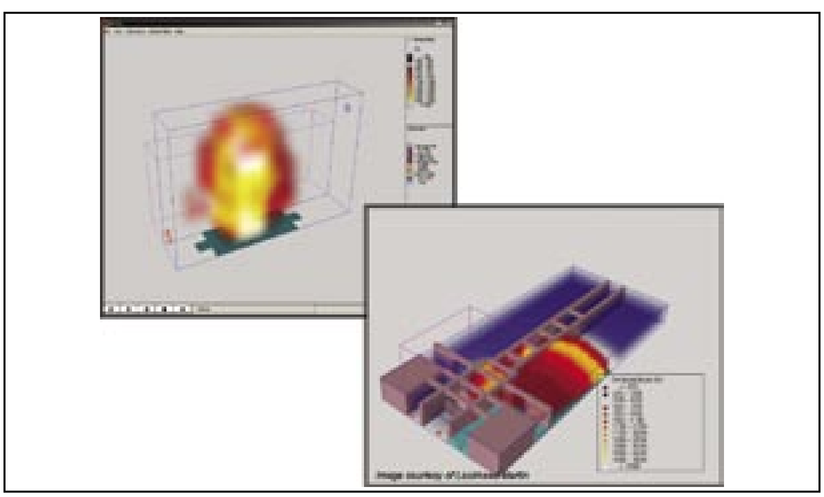


Figure 4. FPM 3.2.1 3-D post-processing visualization output

Also, the FPM now has the capability to model fire suppression agents. The FPM version 3.2.1 allows the user to choose from five different fire suppressants: CO_2, H_2O, FM 200, FE–25, and Halon 1301. The fire suppression simulation includes an infrared (IR) sensor and up to five fire suppressant injectors that can be placed anywhere in the dry bay. Fire suppression effects that are simulated in the model include the amount of agent introduced into the dry bay from each injector, suppressant flow for input duration starting at IR sensor response time, and the amount of species present (e.g., fuel, suppression agent, O_2, H_2O, CO_2, CO, HF, CF_2O).

In addition, the FPM 3.2.1 now allows the user to define parameters to characterize a flammable liquid of interest. Prior to this feature, the user had only the option of selecting from a limited number of defined fluids (JP4, JP5, and JP8 fuel and MIL–H–5606 and MIL–H–83282 hydraulic fluids).

Another new capability is the addition of composites to the current list of materials available for modeling the striker plate and dry bay walls. Kevlar, S2 glass, graphite epoxy, BMI, Nylon 66, and polyethylene are now available.

Current programs using the FPM

Several members of the survivability/vulnerability community are currently utilizing the FPM for planning tests, conducting trade analyses, performing vulnerability assessments, running pre-shot predictions, and designing systems. Some of the programs now using the FPM are briefly discussed in the text that follows.

The C–5 Live Fire Test and Evaluation (LFT&E) program, which includes an assessment of the aircraft's survivability to low-altitude small arms and anti-aircraft artillery (AAA); particularly with respect to low-altitude threat-induced onboard fire. The FPM is being used to help estimate the vulnerability of the C–5 and to assist in developing pre-test predictions for later C–5 LFT&E shots. Data collected, as a result of the testing, will be used for further validation of the FPM. Additional information on how FPM is being used for the C–5 LFT&E program may be obtained through Mr. Kelly Kennedy (kelly.kennedy@wpafb.af.mil).

Another group using the FPM is the Joint Strike Fighter (F–35) LFT&E team. The F–35 team has used the FPM to assist in the vulnerability assessment as well as to make pre-shot predictions. Test results from the LFT&E program will also be used for further validation of the FPM model. Additional information on how the FPM is being used for the F–35 LFT&E program may be obtained through Mr. James Rhoads (james.e.rhoads@lmco.com).

Examples of other projects using the FPM include a fire suppression effort at the Naval Air Warfare Center Aircraft Division (NAWCAD), Patuxent River, Maryland. NAWCAD is using FPM for planning fire suppression tests. The model is being used to conduct trade studies by varying parameters, such as different fire suppression agents, fire locations, and ventilation velocities. Additional information on how the FPM is being used for this effort may be obtained through Dr. David Keyser (dkeyser@pax.i-n-s.com). Boeing is also looking at the possibility of using the model for work on future aircraft programs. Additional information on how the FPM is being used at Boeing may be obtained through Mr. Earl Wilhelm (earl.e.wilhelm@boeing.com).

Verification and validation (V&V) effort

The initial verification and validation (V&V) effort for the FPM is being conducted under the direction of the Air Force Aeronautical Systems Center Modeling, Simulation and Analysis Division (ASC/ENM) at Wright-Patterson Air Force Base (AFB) in Dayton, Ohio. The SURVICE Dayton Operation is conducting the effort through development and execution of test cases, with the primary scope being to investigate the individual computations occurring in FPM, not just the end results of ignition probabilities and sustainment. Parameters specific to aircraft fuel tanks and containers are being addressed for armor-piercing incendiary (API), high-explosive incendiary (HEI), and fragment threats.

Future of the FPM

The FPM is continually being improved with enhancements of current capabilities or the addition of new capabilities. Near-term plans for the FPM include the integration of the Ullage Explosion (Ullex) model, the simulation of ignition by fragment flash on the front face of the fuel tank, the simulation of fire suppression by solid aerosol particulates, the inclusion of component heat flux, and the expansion of the user and analyst manuals. These modifications will be included in the next FPM release (version 3.3) tentatively scheduled for the summer of 2004.

The integration of Ullex will expand the FPM's capabilities to allow the user to evaluate the vulnerability of the entire fuel system, including dry bay fires, ullage explosions, and shotlines intersecting both the liquid fuel and ullage. The addition of front-face flash recognizes that new materials used in military targets could react under certain impact and design conditions, providing ignition sources not previously experienced; and the addition of solid aerosols, supplements the simulation of gaseous agents currently modeled. Finally, the component heat flux feature will describe the incident heat flux for individual components, enabling the user to estimate the time of component failure as a function of fire intensity and location.

Other potential enhancements also being considered include the following—

- The simulation of solid materials combustion, including man-made polymers such as composites on aircraft and natural polymers like cellulose in wood. This enhancement would allow the extension of FPM to buildings.

- Inclusion of pilot ignition that involves fire spread through ignition of hot embers or soot. This enhancement would be used mostly (if not entirely) for application to building fires.

- Development of a method to describe FPM target inputs directly from a FASTGEN target description.

- Simulation of secondary ignition due to leakage that is far removed from the primary ignition source.

The release of the FPM version 3.2.1 includes the WINFIRE GUI, 3-D geometry visualization tool (pre-processing), 2-D and 3-D post-processing visualization tools, and an analyst's manual. Anyone interested in using the FPM may obtain the code from the model manager, Mr. Martin Lentz (martin.lentz@wpafb.af.mil). ■

Ms. Kristin Rose is a Chemical Engineer at the SURVICE Engineering Company in Belcamp, Maryland where she is also a member of the SURVICE FireWorks Modeling and Analysis Center Team. Ms. Rose is supporting Navy analysis of aircraft engine nacelle fire suppression agents using the Fire Prediction Model. She is also currently analyzing the effectiveness and survivability characteristics of the Stryker Automatic Fire Extinguishing System (AFES) as part of the Live Fire Test and Evaluation Program. In addition, she provides support to the U.S. Army Test and Evaluation Command's Army Evaluation Center in non-ballistic and ballistic survivability analysis. Ms. Rose has a Bachelor's degree in Chemical Engineering from the University of Delaware, where she is currently working on a Master's Degree of Material Science and Engineering. She may be reached by e-mail at kristin@survice.com or by telephone at 410.273.7722.

C–130 J Live Fire Test & Evaluation (LFT&E) Program Status Report

■ *by Mr. Dan Cyphers and Mr. John Haas*

The C–130J Live Fire Test and Evaluation (LFT&E) program is in its final stage. Since the initiation of the first of six phases of the program in 1997, a significant amount of vulnerability data has been gathered. The final two phases of the program, to be completed in 2004, will provide still more valuable data.

The C–130J represents a unique case of military aircraft acquisition. The aircraft was developed by Lockheed Martin as a commercial, Off-the-Shelf item, and consequently did not go through the normal acquisition milestones that automatically trigger LFT&E. The Air Force and OSD/DOT&E conceived and agreed to a series of tests and analyses to address C–130J LFT&E. The Air Force turned to the expertise provided by its 46th Test Wing Aerospace Survivability and Safety Flight (46 OG/OGM/OL–AC) at Wright-Patterson Air Force Base (AFB), Ohio, to successfully accomplish the C–130J LFT&E program. All ballistic testing has been conducted in the ranges of the 46 OG/OGM/OL–AC Aerospace Vehicle Survivability Facility (AVSF).

The results of a C–130H/J vulnerability analysis completed in 1997 were used as the basis for most of the test and analysis programs conducted as part of the C–130J LFT&E program. The analysis highlighted several areas of known vulnerabilities and identified data voids that prevented a more complete vulnerability analysis. Based on these areas of uncertainty, test programs were planned to gather additional data to better understand potential aircraft vulnerabilities. The final C–130J LFT&E program was comprised of six individual test and analysis programs. Four of the programs, designated Vulnerability Reduction Programs (VRP), were funded by the Air Force. The other two programs were funded by OSD through the Joint Live Fire (JLF) program. The six programs comprising the C–130J LFT&E program are listed below:

- **C–130 VRP Phase I—** Wing Dry Bay Fire Extinguishing Agent Evaluation
- **C–130 VRP Phase II—** Composite Propeller Ballistic Damage Evaluation
- **C–130 VRP Phase III—** Man-portable Air Defense System (MANPADS) Vulnerability Analysis
- **C–130 VRP Phase IV—** Engine Nacelle Fire Extinguishing Evaluation (ENFEE)
- JLF C–130 Wing Hydrodynamic Ram Evaluation (WHRE)
- JLF Mission Abort Analysis

The C–130 VRP Phase I evaluated and demonstrated the effectiveness of fire extinguishing agents in ballistic threat-induced C–130 wing dry bay fires. The program examined three different wing dry bays: wing lead edge dry bays (Phase IA), engine area dry bays (Phase IB), and wing trailing edge dry bays (Phase IC). The test approach first utilized replica hardware to evaluate a variety of agent parameters and then used production hardware to demonstrate the most promising solutions. This Phase I program demonstrated the feasibility of active fire extinguishing agent solutions in the wing dry bays, and generated data that could be used in the design of a fire suppression system. In addition to the vulnerability reduction aspect of the program, the Air Force also incorporated traditional LFT&E testing of production assets to further characterize C–130 wing dry bay fire vulnerability. The C–130 VRP Phase I has been completed, and the test reports and Aircraft Battle Damage Repair (ABDR) reports have been published.

Phase II of the C–130 VRP was initiated to determine the vulnerability contribution of the C–130J composite propeller blades, when those blades are penetrated by a ballistic threat. Six ballistic tests were conducted in Fiscal Year (FY) 2001, utilizing new production R391 composite propeller blades. The composite propeller blades were penetrated with a variety of ballistic threats while subjected to static, structural loading. Loads were applied to approximate centrifugal forces and net bending moments experienced by the blade during a realistic in-flight condition. Each ballistic test involved a propeller blade configuration (pitch of the blade, etc), shotlines, and impact orientation indicative of the simulated flight condition. This Phase II test and evaluation program encompassed nondestructive evaluations; modal surveys; stiffness examinations; a vibration analysis; and fatigue testing, which evaluated the blade using loads experienced throughout a typical return home flight scenario. The evaluations involved the participation of not only 46 OG/OGM/OL–AC, but also several organizations within the Air Force Research Laboratory, Lockheed Martin, Dowty Propellers, and Rolls-Royce Corporation. The data compiled from this program provides a more complete understanding of composite blade vulnerability and allows for an examination of potential aircraft vulnerabilities when a propeller blade is damaged in flight. The test and analysis report has just been published.

Phase III of the C–130 VRP was an assessment of the vulnerability of the C–130J to the MANPADS threat. No standard tools exist to perform vulnerability analyses for MANPADS threats. Thus, the principal challenge in the program was to assemble and exercise a set of tools that would allow for regions of the C–130J to be identified that were most likely to be hit by a MANPADS, and then translate this information into accepted models to perform the vulnerability analysis. This effort extended and expanded the previously completed C–130H/J vulnerability analysis that did not consider the MANPADS threat. The vulnerability analysis was performed for a B Kill level (aircraft falls out of manned control within 30 minutes), using the mission scenario in the previously completed C–130H/J vulnerability analysis. The Modeling System for Advanced Investigation of Countermeasures (MOSAIC) was used to define likely hit-point envelopes. The Computation of Vulnerable Areas and Repair Time model (COVART 4) was then used to determine vulnerable area within these envelopes. The results of the analysis have been briefed to the Air Force and OSD/DOT&E, and the final report has been published.

C–130 VRP Phase IV is currently being conducted to evaluate the effectiveness of the C–130J engine nacelle fire extinguishing system to ballistic threat-induced fires. Test planning for this program is nearing completion, and ballistic testing is currently planned to begin around October 2004. The C–130H/J vulnerability analysis leading to the C–130 VRP assumed that the engine nacelle fire extinguishing system of the C–130J would extinguish any ballistic-threat induced fire and an engine nacelle fire did not present a significant vulnerability risk to the aircraft. However, little or no ballistic test or combat data was available to validate this assessment. Therefore, the ENFEE program will produce valuable data quantifying the effectiveness of the C–130J engine nacelle fire extinguishing system performance against ballistic threat-induced fires in the engine nacelle area. It also will update or validate vulnerability data used in the C–130H/J vulnerability assessment by providing a higher engineering confidence level for sustained fire probabilities and the expected damage.

The JLF C–130 WHRE was conducted to address and analyze structural damage due to ballistic threat-induced hydrodynamic ram in the C–130 wing fuel tanks. Although hydrodynamic ram was not found to be a significant contributor to vulnerability in a 1997 C–130H/J comparative vulnerability analysis, there were uncertainties associated with this assessment.

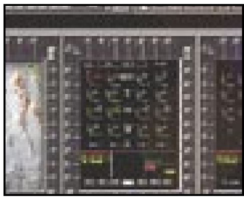
The WHRE program used two C–130H outer wing sections as test articles, but due to the structural similarities to the C–130J model, the results are applicable to both aircraft. The wings were subjected to simulated flight loads representative of the in-flight test condition examined in the C–130H/J vulnerability analysis. Eight ballistic tests were conducted on the first test article, and six ballistic tests were conducted on the second test article. After each test, ABDR technicians repaired the damage. ABDR engineering support was used to design repairs so wing integrity could be maintained for subsequent tests. With the assistance of Lockheed Martin, a residual strength analysis was performed after each test to determine if the structural damage inflicted on the wing resulted in a reduction in load-carrying capability and, if so, to what level. The maximum load-carrying capability of the damaged wing was determined for comparison with the undamaged wing. Flight limitations were also determined for the damaged wing. Some potential methods for improving the C–130 wing's hydrodynamic ram tolerance were also generated. The report for this program is complete, along with an ABDR report, and both have been published.

Finally, a JLF C–130J Mission Abort Analysis is underway. The analysis and final report are scheduled to be complete in 2004. The mission abort kill level was not addressed in the original C–130H/J analysis, and this effort is being conducted to produce data necessary for a full mission abort vulnerability assessment. Critical component lists, fault trees, and a failure modes and effects criticality analysis are intended outcomes of the analysis.

The C–130J LFT&E program will soon finalize an extensive assessment of data voids and vulnerability issues remaining after the 1997 C–130H/J vulnerability analysis. This new data will provide for more accurate and comprehensive C–130 vulnerability evaluations in the future, including a fleet-wide C–130 vulnerability analysis to be conducted as part of LFT&E for the C–130 Avionics Modernization Program (AMP). ■

Mr. Dan Cyphers is a Senior Engineer and Manager for Skyward, Ltd. in Dayton, Ohio. He has a Bachelor of Mechanical Engineering degree and an M.S. in Aerospace Engineering, both from the University of Dayton. Mr. Cyphers has been involved in aircraft survivability/vulnerability testing and analysis for close to fifteen years, including ballistic live fire test and evaluation and vulnerability reduction concept evaluation. His experience also includes advanced material evaluations and survivability analysis for space-based ballistic missile defense applications. Mr. Cyphers may be reached by e-mail at dcyphers@skywardltd.com or by telephone at 937.252.2710, x102.

Mr. John Haas is the Principal Engineer for Skyward, Ltd., based in Dayton, Ohio. He has a Bachelor of Science degree in Engineering Physics from the Ohio State University and a Masters of Business Administration degree from Wright State University. Mr. Haas's career in aircraft survivability/vulnerability testing and analysis has spanned over a decade, including ballistic live fire test and evaluation of many Air Force aircraft, and vulnerability reduction concept evaluation. Mr. Haas may be reached by e-mail at jhaas@skywardltd.com or by telephone at 937.252.2710, x104.



C–130 Avionics Modernization Program (AMP)

and LFT&E (Live Fire Test & Evaluation) Program

■ *by Mr. Scott Frederick and Mr. John Murphy*

The C–130 Avionics Modernization Program (AMP) will upgrade most Combat Delivery and Special Mission C–130 aircraft. The C–130 AMP is part of a multi-phase strategy to modernize the C–130 fleet, comply with Global Air Traffic Management (GATM) 2005 and Air Force Navigation and Safety (Nav/Safety) requirements, and bring all C–130 aircraft (except C–130J) to a common configuration. The C–130 AMP specifically addresses the C–130 avionics and any other associated changes necessary to support the new avionics (see Figure 1 on page 28). The C–130 AMP does not address aircraft structural changes, engine changes, or electrical power and cooling changes other than those required to support the new avionics. These systems will be addressed in other phases of the modernization strategy.

Five major areas are addressed by the C–130 AMP: standardization, reduced manpower requirements, GATM 2005, nav/safety, and reliability, maintainability, and sustainability upgrades. The program will be accomplished through a comprehensive cockpit modernization of the C–130 fleet, by replacing aging, unreliable avionics, and by adding and integrating additional equipment, as necessary. The C–130 AMP is applicable to combat delivery aircraft that span multiple models purchased by the Air Force over a thirty-year period, including the C–130E, C–130H1/H2/H3, and multiple combat delivery Mission Design Series (MDS) variants. It is also applicable to special mission C–130 variants. The modification will reduce differences in equipment among the various C–130 configurations (including AC–130, EC–130, HC–130, LC–130 and MC–130) to the maximum extent possible.

The requirements of Title 10, Section 2366, "Major Systems and Munitions Programs: Survivability Testing and Lethality Testing Required Before Full-Scale Production," become important for acquisition programs like the C–130 AMP. This requirement, enacted by the United States Congress, is also known as the Live Fire Test (LFT) law. It mandates full-up, live fire testing for new acquisition and product improvement programs to meet specific conditions. The law also establishes provisions for waiving full-up, system-level testing if certain additional criteria are met. In the case of the C–130 AMP, agreeing with Air Force recommendations, the Office of the Secretary of Defense (OSD) determined that the program met the conditions contained in the law, and the program was designated as a "covered" product improvement program.

A key prerequisite for C–130 AMP to move beyond the Technology Development acquisition phase and into the System Development and Demonstration phase requires completion of the program's Test and Evaluation Master Plan (TEMP). An important part of the TEMP contents for any covered system is how Live Fire Test and Evaluation (LFT&E) requirements will be addressed. As the C–130 AMP acquisition progressed, the C–130 AMP Development System Office (ASC/GRB) recognized the AMP met the criteria to be considered a covered product improvement. At the same time, ASC/GRB decided full-up testing was not appropriate. Thus, a waiver from full-up, system-level testing was requested, and an Alternative LFT&E Plan was developed and incorporated into the TEMP, as an appendix. The development of the Alternative LFT&E Plan involved a great deal of coordination between the Air Force and OSD. To assist ASC/GRB in defining a responsive LFT&E program, the 46th Test Wing's Aerospace Survivability and Safety Flight (46 OG/OGM/OL–AC), who is the vulnerability responsible test organization (RTO) for Air Force LFT&E programs, and its support contractor, Skyward, Ltd., were brought onboard to support the effort. After extensive discussions, agreement was reached on the scope and content of the AMP LFT&E program, and the alternative strategy is now outlined in the TEMP. The current TEMP was approved in October 2002. An updated TEMP is currently in review. The LFT&E program is scheduled for completion, as required, prior to the Full-Rate Production decision milestone, which is currently April 2008.

The alternative strategy outlined in the TEMP assesses the impact of new avionics, and any necessary aircraft changes due to AMP equipment installation, on the vulnerability/survivability of a C–130 AMP modified Combat Delivery aircraft. Since the C–130 AMP provides for the installation and test of new and updated avionics systems, with a minimal effect on other components, it is not expected to significantly impact the attrition kill vulnerability characteristics (K, A, and B kill levels) of the C–130. It will, however, impact C–130 survivability through modifications to the electronic warfare and situational awareness capabilities of the fleet, and through potentially significant changes to mission avionics vulnerabilities. During C–130 AMP Engineering and Manufacturing Development (EMD), vulnerability reduction methods will be analyzed to identify cost effective means to improve avionics survivability. The LFT&E program will assist in this effort and provide a comprehensive analysis of C–130 AMP aircraft vulnerabilities due to ballistic threats.

continued on page 28

Mr. Frederick Marsh

Young Engineers in Survivability

by Mr. Lex Morrissey

The Joint Aircraft Survivability Program Office (JASPO) is pleased to recognize Mr. Frederick Marsh as our next Young Engineer in Survivability. Fred is one of the bright young engineers at the U.S. Army Research Laboratory (ARL), Survivability/Lethality Analysis Directorate (SLAD), who is doing an excellent job supporting the Joint Live Fire (JLF) Air and Joint Aircraft Survivability (JAS) programs for JASPO, Army Live Fire Test and Evaluation (LFT&E), and Army Vulnerability/Lethality Research and Development (R&D) programs.

After graduating from the Loyola College of Baltimore in 1987 with a Bachelor of Science Degree in General Engineering, Fred came to work for the U.S. Army Ballistic Research Laboratory (later absorbed into ARL) in the Systems Engineering and Concepts Analysis Division (SECAD), at Aberdeen Proving Ground (APG), Maryland in 1990.

Among his initial assignments, Fred worked as a ballistic vulnerability experiment project engineer and vulnerability analyst. He proposed, planned, and executed ballistic vulnerability/lethality experiments to support ARL's mission and external customer (JLF, JASPO, PEO Aviation, Industry) requirements. After some time in the SECAD, he was assigned to a developmental detail where he served as a project engineer and liaison between the SECAD and the Vulnerability/Lethality Division (VLD) Air Systems Branch (ASB) for the M830A1 Multi-Purpose Anti-Tank (MPAT) round LFT&E lethality program. In this role, he was instrumental in the development of a cooperative analysis and test program for the MPAT munition and conducted the first Live Fire Test (LFT) with the round versus a helicopter target (UH–1 Huey). The results from his tests served as the basis for developing the subsequent LFT program of the MPAT round versus a full-up Mi-24 Hind helicopter.

In 1993, Fred transferred to the ASB and transitioned to project engineer for the first LFT&E of a U.S. Army helicopter—the AH–64D Longbow Apache. For this dual phase program (hydraulic subsystems and mast-mounted assembly), he was responsible to investigate the hydraulic subsystems and prepare the detailed test plan (DTP); design and lead the fabrication of the test fixtures; lead the conduct all of the LFTs; and prepare the final test report (FTR). The Longbow Apache LFT&E program was successfully completed in April of 1995 and produced significant vulnerability information for the Apache hydraulic subsystem. The test series demonstrated the robustness of the aircraft hydraulic subsystem and eliminated the need for proposed vulnerability reduction measures. At the conclusion of the Longbow Apache LFT&E program, Fred became the lead project engineer for the Special Operations Aviation (SOA) Aircraft (MH–60K and MH–47E) LFT&E program. This program provided significant vulnerability information on the auxiliary and main fuel subsystems, and resulted in the modification of all MH–60K and MH–47E SOA aircraft to incorporate nitrogen inerting in all of the fuel tanks, which provided significant reduction of the vulnerability to fuel fires and explosions from many threats.

With the completion of the Apache and SOA test series, Fred moved to lead engineer for several JLF Air test programs to include Hellfire/Stinger ballistic vulnerability; AH–1 Cobra fuel subsystem vulnerability; U.S. 20-mm PGU-28/B Semi Armor Piercing HigH–Explosive (SAPHEI) projectile lethality; and UH–60 Black Hawk Tail Rotor Subsystem/Aft Structure ballistic vulnerability. For all these programs, Fred continued to exhibit his teamwork attitude and acceptance of suggestions to improve the quality and substance of the experiments. The Hellfire/Stinger and AH–1 Cobra fuel subsystem vulnerability programs served to collect experimental data and analyze the vulnerability of the respective systems to small arms threats. The objective of the PGU–28/B SAPHEI projectile lethality program was to collect experimental data and analyze the lethality of the PGU–28/B projectile versus foreign rotary wing aircraft. In addition to the lethality information gathered from this program, results proved instrumental in providing to the Office of the Secretary Defense (OSD)/Director of Operational Test and Evaluation (DOT&E) and others, key information for investigating and resolving suspected discrepancies with the projectile. Data generated from this test series is also currently being used to support development and testing of the U.S. XM–1031 20-mm projectile, tentatively planned to be implemented on the RAH–66 Comanche helicopter. Throughout all these programs, Fred displayed his professionalism by actively updating all participants on the status of all test activities.

JLF Air PGU–28/B SAPHEI projectile lethality program

In 1999, Fred served as lead project engineer for two significant tests supporting development of the Army's state-of-the-art RAH–66 Comanche helicopter Main Fuel Subsystems Milestone II Exit Criteria test series and the

Tail-Cone and Shroud Risk Reduction test series. Both efforts were successfully completed in 1999 and provided the first ballistic vulnerability information for the Comanche helicopter. As a direct result of these test series, modifications were made to the Comanche helicopter to improve the systems survivability in the battlefield.

JLF Air UH–60M Blackh Hawk fuel subsystem vulnerability program

In 1997 Fred Marsh was selected as ARL/SLAD's system leader for UH–60M Blackhawk Helicopter Modernization program. In this role, he is responsible for planning and coordinating the complete SLAD survivability program supporting the UH–60M system for chemical/biological, nuclear, electronic, and conventional ballistic threats. Fred also leads SLAD's ongoing test and analysis effort for the Joint Army/Navy H–60 LFT&E program, and he is the test engineer for the main fuel subsystems, T700–701C engine, crashworthy extended-range fuel subsystem, and main rotor blade LFTs. In the early development of the UH–60M Black Hawk LFT&E program, OSD/DOT&E suggested that commonality between Army Black Hawk and Navy Seahawk helicopter program schedules and materiel presented a unique opportunity for the two services to jointly perform LFT&E by sharing test responsibilities, assets, costs, and data. To develop this Joint Army/Navy H–60 Helicopter LFT&E program, Fred conducted several component, subsystem, and system level engineering comparative analyses that investigated both the Black Hawk and Seahawk aircraft. Based on those analyses, the first Army/Navy LFT&E program was formulated. In support of AEC and Navy LFT evaluators, he played an instrumental role in identifying, analyzing, and selecting the Black Hawk and Seahawk components and subsystems in order to formulate the scope of the LFT effort. In November 2002, Fred received the ARL Achievement Award for Analysis for this effort. An integral part of this award was the recognition of Fred's innovative efforts to include aviation battle damage assessment and repair as a priority task of the Black Hawk program. He coordinated with the U.S. Army Aviation Logistics School (USAALS), and developed a program to reconstruct damaged aircraft from salvageable components of other aircraft with the help of USAALS students. These reconstructed aircraft serve as targets for both the Navy and Army portions of the LFT. He further developed the program to include the use of USAALS students on site to perform damage assessment and acceptable aircraft repairs. This program has led to development of certain damage repair techniques that have been accepted and passed on to fielded units.

Fred Marsh receiving the ARL Achievement Award for Analysis from MG Doesburg, Commander SBCCOM, and Dr. Whalin, Director ARL

In April 2002, Fred was selected as the lead for the initial Joint Combat Assessment Team (JCAT) exercise. The JCAT was assembled to assess, collect, and report combat data from U.S. Army and Special Operations Aviation (SOA) aircraft damaged during the Afghanistan conflict, an effort that was coordinated by the Army Evaluation Center. Fred assembled and instructed a team of four from the U.S. Army Aviation Logistics School, the U.S. Air Force, and contract personnel. This team collected critical battle damage data and conducted interviews with members of the 160th Special Operations Command (SOCOM), to include pilots and flight crew from actual Operation Enduring Freedom missions. This effort has led to the investigation of several vulnerability issues of the aircraft that are presently being addressed by the SOCOM community. Fred continues to serve as a member of the JCAT team (now sponsored by JASPO) which has gone on to perform similar missions on a variety of aircraft that have returned from other conflicts in Afghanistan and Iraq.

Mr. Marsh serves as the Army co-chair on the Joint Aircraft Survivability program Vulnerability Reduction Subgroup Fuels Committee. He has authored more than 25 ARL and JLF technical reports and is a frequent presenter at survivability symposia and conferences. In October 2003, Fred was selected as Team Leader for ARL/SLAD's Experimental Facility team.

In his leisure time, Fred enjoys the outdoors and its challenges. He is an avid hunter and fisherman. He enjoys bass fishing, tidal water fishing in the Chesapeake Bay, and the occasional offshore fishing trip in the Atlantic Ocean. He is also a devoted football fan and spends his Sundays during the fall watching and attending Baltimore Raven's games. It is with great pleasure that we present Mr. Frederick Marsh as the latest JASPO Young Engineer in Survivability.

Mr. Lex Morrissey received his AB Degree in Physics from Loyola College 1962. He came to work for the Army in 1963 at Nuclear Defense Laboratory (NDL) working with nuclear weapon effects measurements. He then went onto Ballistic Research Laboratory where he worked with directed energy weapons particularly with the measurement of HEL damage to optic sensors. In 1988, he started on the Dome Street program and has been associated with the JLF Ground since that time. He went to ARL in 1992 where he was the mission area coordinator for air defense and then in 1998 returned to ballistic work as the branch chief of the Experimental Design, Conduct, and Analysis Branch. Mr. Morrissey is also the mission area manager for Aviation Systems for Survivability/Lethality Analysis Directorate (SLAD). He returned to the front office of ARL/SLAD/BND in July 2003 and retired from civil service in January 2004. ■

continued from page 25

Figure 1. Current C–130 AMP cockpit installation (December 2003)

The C–130 AMP LFT&E program strategy was developed through an examination of the key vulnerability issues posed by the AMP upgrade. First, the vulnerability of the C–130 AMP modifications needed to be evaluated. However, to truly quantify the effect of the system changes, an entire aircraft vulnerability assessment would need to be conducted. Unfortunately, a vulnerability assessment for a single C–130 variant may not cover the overarching issue of C–130 AMP vulnerability across the fleet. Therefore, an analysis is required to consider design differences across the fleet and the effect of these differences on vulnerability. This examination will need to consider vulnerability lessons learned from other recent test and evaluation programs, including the C–130J and KC–130J LFT&E programs, and any recently obtained combat data.

To address the aforementioned C–130 AMP vulnerability issues, an LFT&E alternative strategy was conceived consisting of four major elements: AMP electronics data analysis and, if warranted, AMP electronics ballistic testing, AMP attrition/mission abort vulnerability assessment, and C–130 total system vulnerability analysis. The first element of the AMP LFT&E program, will make use of AMP contractor system integration facility/system integration laboratory (SIF/SIL) tests of the AMP avionics components and electrical systems. Fault insertion tests will be used to simulate damaged components and examine effects on the overall aircraft operation. In cases where critical component designs or configurations cannot be adequately analyzed through SIF/SIL testing or analysis, recommendations may be made for ballistic live fire testing, the second element. The purpose of these tests will be to significantly reduce uncertainties and examine synergistic or cascading effects resulting from ballistic impact.

These first two elements of the LFT&E strategy will provide input data for a series of COVART/FASTGEN vulnerability assessments of the aircraft. Attrition vulnerability assessments (K, A, and B kill levels) will be conducted on a C–130H2 Combat Delivery configuration, both before and after AMP modifications, to assess the effect of these changes. In addition, a mission abort vulnerability assessment will be conducted of the same aircraft after AMP modifications. Threats examined in the assessments will include armor piercing incendiary and high explosive incendiary projectiles, warhead fragments, and a single Man-Portable Air Defense System threat. The C–130H2 variant was chosen based upon the number of this fielded system in the inventory compared to other variants, and because its design provides the most applicability across the fleet. Finally, the test and evaluation results, vulnerability assessment information provided by this program and other C–130 efforts, along with combat data and updated threat information, will be compiled in a C–130 system level vulnerability analysis report evaluating vulnerabilities across the fleet. This C–130 fleet-wide system level vulnerability analysis "capstone" report will be the culmination of the LFT&E effort.

A full and open competition of the AMP development contract resulted in an award to The Boeing Company on July 30, 2001. Boeing is not only participating in the LFT&E program, but is also currently executing a survivability program designed to ensure the existing survivability of the C–130 fleet, so as to not degrade the C–130 by installation of the AMP avionics. Boeing is identifying potential vulnerability reduction design features for all mission critical avionics components, determining the relative contribution of each feature to improvements in mission survivability, and utilizing cost/benefit analysis to select features for incorporation into the design. Boeing's survivability program is complementary to the Air Force's LFT&E program. ASC/GRB arranged for portions of the LFT&E program to be performed by Boeing, as the AMP prime contractor. Boeing is working in cooperation with 46 OG/OGM/OL–AC, who will guide and carry out portions of the LFT&E program, including any warranted ballistic testing.

The Air Force LFT&E and Boeing survivability programs are tightly integrated in order to yield the outputs required for preparation of the C–130 System Level Vulnerability Analysis Report. This document, LFT&E accompanying data, and the final AMP design will provide the basis for OSD's C–130 Live Fire Test report to Congress, which is required prior to the approval of the AMP aircraft entering Full–Scale Production. ■

Mr. Scott Frederick received his Bachelor of Arts degree in Mathematics from the University of Cincinnati. He is a Senior Analyst with Skyward, Ltd., based in Dayton, Ohio. He has been involved in aircraft survivability/vulnerability analysis for fifteen years and testing for over eight years. He has led or participated in conducting vulnerability analyses and planning/reporting on live fire test programs of a number of U.S. Air Force systems. He may be reached at sfrederick@skywardltd.com.

Mr. John Murphy is the Acting Technical Director of the Aerospace Survivability and Safety Flight (46 OG/OGM/OL–AC), Wright-Patterson AFB, OH. Mr. Murphy has almost twenty years of aerospace survivability experience, including working LFT&E programs since 1987 and Joint Live Fire programs since 1998. He is the Joint Test Director for Joint Live Fire Aircraft Systems. John has a B.S. in Mechanical Engineering from the University of Cincinnati and a M.S. in Mechanical Engineering from the University of Dayton. He may be reached at 937.255.6302, x233 (DSN 785.6302, x233), or by e-mail at john.murphy@wpafb.af.mil.

JLF/Air

by Mr. Jeffrey Wuich and Mr. John Murphy

The Joint Live Fire (JLF) Program was initiated by the Office of the Secretary of Defense (OSD), in March 1984, to establish a formal process to test and evaluate fielded U.S. systems against realistic threats. The primary objective is to assess the vulnerability of fielded U.S. armored vehicles and combat aircraft to threats likely to be encountered in combat, and to evaluate the lethality of fielded U.S. munitions against realistic targets. The program continues today under the auspices of the Deputy Director, Operational Test and Evaluation/Live Fire Testing (DDOT&E/LFT).

The JLF/Air projects for Fiscal Year (FY) 2004 will provide empirical data on the vulnerabilities of some of our currently fielded aircraft platforms. This important information will be made available to the test and evaluation community, and to system program managers and users. The FY04 JLF/Air Program consists of vulnerability tests and assessments on the following rotorcraft and fixed-wing aircraft: the AH–1, CH–47D, CH–53E, H–60, and the Predator unmanned aerial vehicle (UAV). Large turbofan engine vulnerability to the MANPADS threat will also be initiated in FY04.

JLF/Air FY04 program

Rocket propelled grenade (RPG) testing—As we have seen in recent armed conflicts, our front-line helicopter systems are susceptible and vulnerable to attack from readily available threats. One of the threats of primary interest to the vulnerability test and evaluation community is the RPG. The JLF/Air FY04 Program will investigate the vulnerability of front-line helicopters to this threat by testing the AH–1S Cobra aircraft. The goal of this effort is to identify potential survivability enhancements for helicopters encountering this threat.

CH–47 testing—In FY04, JLF/Air will complete an effort in partnership with the Cargo Helicopter Program Manager (PM), the Department of Defense (DoD) and commercial armor developers, to design, manufacture, and qualify a shield that will reduce the probability of fuel fires resulting from small caliber projectile impacts on the engine fuel feed shutoff valve, located in the CH–47D Chinook helicopter. This effort will provide information to aid combat mission planning, increase aircraft/aircrew survival and effectiveness in combat, aid battle damage assessment repair training, and provide design recommendations, to reduce the ballistic vulnerability of the fuel feed shutoff valve. The overall results are applicable to two fielded Army H–47 models (i.e., D and E; the latter is a special operations aircraft that has seen extensive combat use in Afghanistan and Iraq) and the future production F model.

CH–53 testing—In FY04, JLF/Air will enter the second year of a multi-year investigation into the vulnerability of the CH–53E platform. This effort will provide information to aid combat mission planning, increase aircraft/aircrew survival and effectiveness in combat, aid battle damage assessment repair training, and provide vulnerability reduction recommendations. In FY04, ballistic tests will be conducted against CH–53E rotor and drive subsystems (main and tail rotor blades, pylon fold, tail drive shaft) under representative dynamic loads. These tests will be used to gather damage data, and perform post-damage operating endurance testing on dynamic components to evaluate the reduction or loss of dynamic flight load capability.

H–60 testing—In FY04, three H–60 efforts are funded under JLF/Air; the dry bay foam vulnerability reduction alternatives, improved durability gearbox (IDGB) run-dry ballistic vulnerability tests, and the H–60 engine nacelle fire extinguishing system effectiveness against ballistic threats. These efforts will provide information to aid combat mission planning, increase aircraft/aircrew survival and effectiveness in combat, aid battle damage assessment repair training, and provide vulnerability reduction recommendations. The results of this project will be applicable to all tri-service H–60 aircraft, and to future production variants including the Army's UH–60M model.

Predator testing—In FY04, the JLF/Air Program will conduct system vulnerability testing of a Predator fuselage and subsystems (fuel, propulsion, and control) replica, before and after select vulnerability reduction features are in place. In keeping with the DDOT&E/LFT's desire to more closely integrate the JLF program to other DDOT&E investment programs, shotlines for this effort, will be based on the COVART analysis previously completed under the JASPO Predator Vulnerability Analysis (FY03). The COVART analysis identified vulnerable areas in the current Predator design that can be addressed in future versions. This project directly supports the UAV Program Office (ASC/RAB, WPAFB) in identifying vulnerability reduction improvements that can be made to present, or future blocks of the aircraft. These lessons learned can be applied to other UAVs/UCAVs as well.

Large Turbofan Engine Testing—In FY04, JLF/Air will initiate a multi-year effort to investigate the vulnerability of the CF–6 large turbofan engine to MANPADS. The following long-standing issues will be addressed—

1. What is the inherent vulnerability of an operational CF–6 engine hit by a MANPADS?

2. How does the hit-point and damage-state compare to pretest predictions?

3. How does the damage affect engine operation and thrust?

4. How will the thrust alteration affect safety-of-flight?

5. If damage produces a kill, what is the kill mechanism?

Test planning will occur in FY04. Test results from this effort will support large aircraft (i.e., C–17, KC–767, and E–10A) operational risk assessments and vulnerability analyses leading to improved warfighter protection. Results of large engine characteristics to MANPADS impact and detonation identified during this effort will be used to feed future large engine design and evaluation requirements.

JLF/Air FY03 products

Below is a list of products generated from the JLF/Air FY03 Program.

1. CD-ROM containing JLF/Air minutes and presentations from the May 6–9, 2003 JASPO Meeting in Nashua, New Hampshire.

2. JLF/Air presentations from the October 20–24, 2003 JASPO Integrated Program Review (IPR) Meeting at Nellis AFB, Nevada.

3. JLF/Air FY03 Tracker and Quarterly Progress Reports

4. Detailed Test Plans

   a. JLF–TP–3–02(A) "AH–1 Vs. RPG (Army)"

   b. JLF–TP–3–02(N) "AH–1 Vs. RPG (Navy)"

   c. JLF–TP–3–02(AF) "AH–1 Vs. RPG (Air Force)"

   d. JLF–TP–3–03 "CAS Aircraft Vs. 35mm"

   e. JLF–TP–3–04 "H–60 Tail Rotor Subsystem Vulnerability Tests - Phase II"

   f. LF–TP–3–05 "CH–53 Vs. AAA"

   g. JLF–TP–3–07 "H–60 Engine Nacelle Ballistic Fire Suppression"

   h. JLF–TP–3–08 "Predator Wing"

   i. JLF–TP–3–09 "Chinook Fuel Feed Plumbing VR Armoring"

5. JLF/Air Final Reports published in FY02 and FY03

   a. JLF–TR–87–08 "UH–60A Main Rotor Blade Vulnerability Tests (U)"

   b. JLF–TR–97–01 "Dynamic Helicopter Blade Ballistic Impact Test (U)"

   c. JLF–TR–98–01 "FY98 JLF/Air Detailed Test Plan Book (U)"

   d. JLF–TR–99–01 "Dynamic Modeling of a Ballistically Damaged Helicopter Rotor Blade (U)"

   e. JLF–TR–01–02 "C-130 WHRE Vulnerability Report (U)"

   f. JLF–TR–01–03 "C-130 WHRE ABDR Report (U)"

   g. JLF–TR–01–04 "JLF Metal Mesh – Phase I (U)"

6. JLF/Air Final Report Tracking Spreadsheet

7. JLF/Air FY04 Proposed Program

8. Articles for JASPO Survivability Newsletter

9. Collected inputs from the JLF/Air Deputy Test Directors in support of—

   a. The annual DOT&E Report to Congress.

   b. Year end close-out status for all JLF/Air efforts.

   c. Developing a list of FY03 JLF/Air products.

   d. JLF/Air SOWs and FRWs to JASPO.

   e. Preparing JTD briefings for IPR and PMSG Meetings, Presentations to Mr. Miller, etc.

   f. Survivability short course.

   g. The new JLF/Air Logo.

JLF/LFT Test plan and final report guide

It has been twenty years since the JLF Test Plan and Final Report Guide located in the original JLF Admin Handbook has been revisited. This guide contains brief guidance on creating a JLF Test Plan and Final Report, but there is still no standard format for Live Fire test plans and final reports. There have been a number of lessons learned in the past twenty years (from both JLF and LFT) that can be used to update this guide. As such, JASPO has funded an effort to update the JLF Test Plan and Final Report Guide to include LFT planning and final report guidance. It was recommended that the Survivability/Vulnerability Information Analysis Center (SURVIAC) author this guide, to ensure consistency in data recording, collection, storage, and reporting. SURVIAC is a centralized information resource for all aspects of non-nuclear survivability, lethality, and mission effectiveness activities. SURVIAC has been supporting the JLF Program since 1985. This effort was initiated in January of 2004 and will be completed by the end of 2004.

JLF Air
JOINT LIVE FIRE
AIRCRAFT SYSTEMS

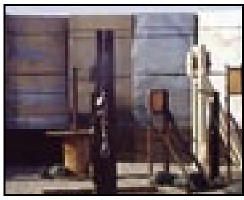
New JLF/Air logo and video

Ms. Christina McNemar and her creative and promotional team (Booz Allen Hamilton) have done an excellent job creating the new JLF/Air Logo (see figure above). The new logo is crisp, clean, neat, and shows well on presentations. It signifies that JLF/Air is responsible for conducting tests to investigate the survivability of fixed-wing, rotary-wing and UAV weapon systems. Congratulations to Christina and team on a job well done!

It has been almost twenty years since the JLF/Air Program video has been updated. A new JLF/Air video will be created this year as well. A first set of ideas for the video have been developed. As we work through the details, we will provide JLF/Air stakeholders with the opportunity to review and comment on the video before we enter into final production. We're looking forward to completing this effort by the end of 2004. ■

Mr. Jeffrey Wuich, an associate at Booz Allen Hamilton, working in support of the SURVIAC, provides technical and administrative support to the JLF/Air. Mr. Wuich has over 14 years of aerospace survivability experience. Jeff received his Bachelor of Science in Aerospace Engineering, from Iowa State University in 1988, and his Master of Science in Mechanical Engineering, from the University of Dayton in 1992. He is a member of the National Defense Industrial Association (NDIA). He may be reached at 937.255.3828, x259 (DSN 785.3828, x259), or by e-mail at wuich_jeff@bah.com.

Mr. John Murphy is the Acting Technical Director of the Aerospace Survivability and Safety Flight (46 OG/OGM/OL–AC), Wright-Patterson AFB, Ohio. Mr. Murphy has almost twenty years of aerospace survivability experience, including working LFT&E programs since 1987, and Joint Live Fire programs since 1998. He is the Joint Test Director for Joint Live Fire Aircraft Systems. John has a Bachelor of Science in Mechanical Engineering, from the University of Cincinnati, and a Master of Science in Mechanical Engineering, from the University of Dayton. He may be reached at 937.255.6302, x204 (DSN 785.6302, x204) or by e-mail at john.murphy@wpafb.af.mil



Assessment of Rocket Propelled Grenade (RPG) Damage Effects

on Light Rotorcraft

by Mr. Patrick O'Connell, Mr. Robert Kunkel, and Mr. Hau V. Nguyen

Developed during the 1960s, the Rocket Propelled Grenade (RPG) is a shoulder-fired munition that was designed to defeat armored targets (see Figure 1). Historically, RPGs have been the most common and effective infantry weapon against ground targets such as armored vehicles, trucks, bunkers, and soldiers in the field.

Figure 1. Typical RPG outside its launcher

The proliferation of RPGs has made them the weapon of choice in contemporary conflicts. While RPGs were designed to defeat armored ground targets, any target of opportunity is a candidate for attack with an RPG—most recently that even includes hotels. A main concern is the RPG use against low-flying helicopters, as seen in all of the recent conflicts including those in Somalia, Afghanistan, and Iraq. The most publicized incident was when U.S. Army Blackhawk helicopters were attacked by several RPGs in Mogadishu during the 1993 Somalian conflict, which was later documented in the book and movie "Black Hawk Down." The use of RPGs against helicopters is not a recent innovation—in fact, there were over 300 reported cases of helicopters damaged by RPGs during the war in Vietnam.

Even though the RPG has a long history of use against helicopters, there is surprisingly little test data. To remedy this, the Director of Operational Testing and Evaluation (DOT&E) sponsored a Joint Live Fire tri-service program to assess the vulnerability of U.S. military helicopter systems (as represented by the AH–1S) to rocket-propelled grenades. Primary interests of the program include RPG fuzing on soft targets (i.e., the helicopter skin), expected blast and fragment damage caused by the RPG self destructing near the helicopter, and the inherent vulnerability of an operational helicopter to a RPG. This program is being conducted in three phases with the cooperation of the U.S. Army, Navy, and Air Force. The Army has conducted tests to determine the fuzing characteristics and damage effects of RPGs fired against an AH–1S. The Navy has conducted tests to determine the damage mechanisms of an RPG warhead self-destructing in close proximity to the aircraft; and the Air Force will conduct RPG vulnerability tests against a fully operational helicopter later this year.

Phase One— RPG fuzing characteristics

Phase one of the test program, conducted by the U.S. Army Research Laboratory (ARL) at Aberdeen Proving Grounds, Maryland, determined the sensitivity of the RPG's fuzing against a helicopter's thin skin and gathered empirical data on the vulnerability of the helicopter's systems. A total of four shots were accomplished against a non-operational AH–1S—one each at the cockpit, the vertical stabilizer, the tail boom where it interfaces with the fuselage, and the aft fuel cell (see Figure 2 for setup).

Instrumentation consisted of exterior blast gauges to record the free field blast, pressure transducers to measure blast overpressure in cockpit, thermocouples and heat flux gauges to determine thermal environment in cockpit, strain gauges in the area of jet impact, and radar to record RPG striking velocity (see Figure 3 for results of blast).

All shots were successfully completed and the results are currently being documented.

Figure 2. ARL's test set-up

Phase Two— Near-miss RPG detonation

Phase two of the test program, accomplished by the Naval Air Warfare

Center at China Lake, California, consisted of a combination of arena tests and full-scale AH–1S tests, to collect data including fragment sizes, spray patterns, blast effects, and shape-charge jet penetrations.

Fifteen Celotex bundles were built and placed in a semi-circle, 15 ft from the warhead. Pressure transducers and velocity measurement plates were placed at distances of 5, 10 and 15 ft from the warhead. For tests 1 and 2, the warhead was placed 5 ft above the ground and in a horizontal position. There were several steel plates 4 ft in front of the warhead nose to demonstrate the penetration characteristic of the nose shape-charge. For test 3, the warhead was placed vertically, with the nose pointed to the ground (see Figure 4 for the set-up).

It was seen that the RPG's nose shape-charge was capable of penetrating through several steel layers. There were numerous fragment holes, primarily concentrated at mid-section of the warhead. Fragments consisted of lightweight warhead skin debris. The blast pressure was significant in close vicinity of the warhead.

Figure 3. Results of RPG testing

Figure 4. Arena test set-up, shot 1

Based on results of the arena tests, the helicopter "near-miss" tests were conducted with the warhead detonating at four different positions near the AH–1S helicopter in full hover rotor speed. In test 4, the warhead was placed and detonated at 15 ft from the tail rotor blades of the helicopter. In test 5, the warhead was detonated at 10 ft from the mid-section of the tail boom. In test 6, the warhead was detonated at 7 ft from the main transmission gearbox. In test 7, the warhead was detonated at 5 ft from the pilot cockpit canopy (see Figure 5 on page 34).

Damage from fragment impact was mostly limited to the helicopter outer surfaces such as door panels, access covers, and cockpit canopy. In all four "near-miss" tests, the helicopter continued to operate for several minutes after the warhead detonation.

Phase Three—RPG against operational AH–1

The third phase of the test program, being accomplished by the Aerospace Survivability and Safety Flight located at Wright-Patterson Air Force Base (AFB), Ohio will consist of shooting RPGs against an operational, instrumented AH–1 helicopter. The specific test parameters will be based on the previous testing accomplished by the Army and Navy in their FY03 efforts.

This project will greatly increase the Department of Defense's knowledge on the damage effects that RPGs have on light helicopters. This tri-service investigation is helping to scope the vulnerability of helicopters to RPGs and will provide the basis for follow-on projects, to increase the survivability of these vehicles to this very deadly threat. ■

continued on next page

Figure 5. Fragment damage to access doors, skin, and cockpit canopy, shot 6

Figure 6. Near-miss test setup, shot 6

Mr. Patrick O'Connell is currently a Project Test Engineer at the Air Force's Aerospace Survivability and Safety Flight at Wright-Patterson AFB. He has 20 years experience working in the field of aircraft survivability and Aircraft Battle Damage Repair (ABDR), 11 years of which he was an Air Force Officer. He received his Bachelor of Science in Aerospace Engineering, from Parks College of Saint Louis University, and his Master of Science in Mechanical Engineering, from the University of Dayton.

Mr. Robert Kunkel currently serves as an Operations Research Analyst within the Experimental Design, Conduct and Analysis Branch, Ballistics and NBC Division (BND), Survivability/Lethality Analysis Directorate (SLAD), U.S. Army Research Laboratory (ARL), where he is currently serving as the Project Lead for the JLF Helicopter Vulnerability (AH–1S) to Rocket-Propelled Grenades (RPGs) (Phase I Army).

Mr. Kunkel joined ARL, formerly the U.S. Ballistics Research Laboratory (BRL), in July 1988 as an Operations Research Analyst. He obtained a Bachelor of Science degree in Mathematical Sciences, from Loyola College, Baltimore, Maryland in January 1987.

Mr. Hau V. Nguyen is a vulnerability test engineer at the Naval Air Warfare Center, Survivability Division, China Lake, California. He is currently working on Joint Live Fire tests of AH–1S helicopter and Joint Army-Navy tests on the MH–60 helicopter. He has a Bachelor of Science in Mechanical Engineering, from California State University, Long Beach, California.

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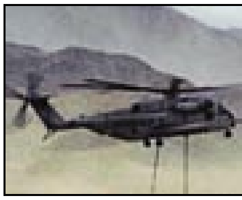


CH–53E to Undergo JLF Testing

by Mr. John Gallagher and Mr. Joe Manchor

The CH–53E Super Stallion is the U.S. Marine Corps' (USMC) heavy lift, multi-mission helicopter. The helicopter's primary mission is the transportation of heavy tactical weapons, equipment, and supplies. Other missions include transportation of troops, evacuation operations, and tactical retrieval and recovery operations for disabled aircraft, equipment, and personnel. The CH–53E is operationally compatible with several classes of Navy ships, including aircraft carriers and amphibious assault ships.

The Sikorsky manufactured CH–53E began service in 1981, as the upgrade from the twin engine CH–53D series aircraft. The CH–53E is easily distinguished from other helicopters by its 3 engines, 7-bladed main rotor, canted tail rotor, and sheer size (fuselage is approximately 74 ft long x 24 ft wide, main rotor diameter is 79 ft). Internal and external payloads are the CH–53E's main business. The helicopter is capable of carrying a 16-ton payload 50 nautical miles, or a 8-ton payload 220 nautical miles, or 55 combat-equipped troops. When air refueled the CH–53E's range is limitless. The CH–53E will be expected to shoulder the USMC's heavy lift missions until at least the year 2014, at which point the CH–53E's future replacement, CH–53X, is scheduled for initial operational capability. The CH–53E will continue to fly until the CH–53X is fully phased in, and realizes full operational capability in the 2020 timeframe.

Presently the CH–53E is proving itself exceptionally worthy during on-going military operations in Afghanistan and Iraq. The CH–53E and its crew have adapted to an increasing number of missions that send it far from base and often behind enemy lines, for example initial wave insertions and long-range reconnaissance. (Previously the helicopter was used primarily for re-supply missions behind the forward line of battle.) It's these kind of new missions that bring the CH–53E within close reach of enemy threats—small arms, anti-aircraft artillery and IR missiles, to name a few—that it was not originally designed to withstand.

A higher probability of exposure to enemy threats has prompted many questions regarding the CH–53E's survivability. Users from the fleet have asked questions such as: "How will my rotor blades, especially after they've been flying for a while, hold up against ballistic impact?," "How vulnerable are the pylon fold hinges?," etc. Unfortunately, there is little recorded combat data and no test data on the vulnerability of the CH–53E to help answer these questions. To develop insight into the CH–53E's vulnerability, and to help in designing the CH–53X, the H–53 Heavy Lift Helicopter Program Office (PMA-261) initiated a multi-year test project to acquire ballistic vulnerability data. The project is sponsored under the Joint Live Fire (JLF) program of the Deputy Director, Operational Test and Evaluation/Live Fire Test (DDOT&E/LFT). This three-year effort will assess the vulnerability of the CH–53E to small arms and anti-aircraft artillery (AAA) threats (12.7mm API through 23mm API/HEI). The objective of this testing is to acquire empirical data on the vulnerability of the CH–53E rotor system, drive train, and fuel system in order to—

1. Develop insights into design changes to reduce the vulnerability of the CH–53E (near–term) and CH–53X (long-term).

2. Enhance the CH–53E Aircraft Battle Damage Repair (ABDR) database.

Figure 1. USMC CH–53E Super Stallion

Figure 2. CH–53E over Afghanistan

3. Validate CH–53E aircraft vulnerability models and analysis techniques.

The first year of this effort (fiscal year 2003) focused on the acquisition of suitable test assets and test planning. The test asset is required to be capable of hovered flight to support the dynamic component testing as described below. Test assets were located at the Aerospace Maintenance and Regeneration Center (AMARC) at Davis-Monthan Air Force Base, including a high-time aircraft that has been specifically identified as the test asset for the JLF test. It has been scheduled for strike in February and then will be delivered in the summer of 2004 to the Weapons Survivability Lab at the Naval Air Warfare Center Weapons Division (NAWCWD) at China Lake, California (where testing will occur). Test planning is on-going.

Actual ballistic testing will commence during the fall of 2004. This first round of testing will evaluate ballistic vulnerabilities of the CH–53E's rotor and drive subsystems. This will include tests of the main and tail rotor blades, pylon fold, and tail drive shaft. For this testing, the aircraft will be placed in a controlled 1–G in-ground effect hover to induce realistic and representative flight loads on the test components. The intent is to determine synergistic and/or cascading damages between aircraft systems as degradation occurs. Post-damage fatigue testing will be completed to evaluate the reduction or loss of dynamic flight load capability.

This technique of helicopter ballistic testing was first successfully demonstrated in July 1996 under sponsorship of the JLF test program, and has since also been utilized by the MH–60R/S and UH–60M LFT programs (see Figure 3). The technique utilizes a special hover test fixture that provides the capability to "fly" the helicopter in a controlled in-ground effect hover. The fixture minimizes the potential for entering hazardous ground resonance conditions, yet holds the aircraft steady to provide accurate aiming of the desired target systems to be tested.

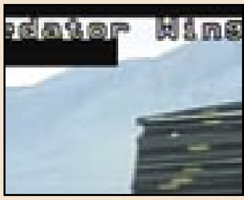
Fiscal year 2005 testing will focus on potential vulnerabilities of the CH–53E's fuel system. Planned testing will evaluate the aircraft's vulnerabilities to fuel starvation, dry bay fire, and ullage explosion. An actual flying helicopter will not be used for this phase of testing. However, a CH–53E fuselage with an operational fuel system (fuel cells, fuel lines, pumps, etc.) will be necessary.

The results of the CH–53E JLF test program will ultimately provide benefit to the warfighter, by answering some nagging questions and improving their aircraft. A better understanding of ballistic vulnerabilities (including cascading effects) will enable the incorporation of vulnerability reduction improvements to the CH–53E. Vulnerability testing results will be especially valuable to the CH–53X team during the early development of that aircraft's low-vulnerability design. ■

Mr. John Gallagher is a mechanical engineer in the Survivability Division (AIR–4.1.8) at the Naval Air Warfare Center Aircraft Division, Patuxent River, Maryland. He is the H-53 survivability Integrated Product Team (IPT) lead. He may be reached at 301.342.0166. or by e-mail at john.p.gallagher@navy.mil.

Mr. Joe Manchor is a mechanical engineer in the Survivability Division (AIR–4.1.8) at the Naval Air Warfare Center Weapons Division, China Lake, California. He brings a wealth of vulnerability expertise to the H–53 team from numerous Navy programs (V–22, H–60, H–1). He may be reached at 760.939.4622 or by e-mail at joseph.manchor@navy.mil.

Figure 3. Dynamic helicopter ballistic testing (Left: AH–1, Right: H–60)



Predator Wing Ballistic Test

■ by Mr. Jim Young and Mr. Neil Hamilton

The General Atomics Aeronautical Systems Inc's Predator Unmanned Aerial Vehicle (UAV) has ushered in a new era in surveillance, reconnaissance, targeting, and attack capabilities while significantly lowering the risk to humans at the controls. UAVs were originally seen as an innovative yet attritable and inexpensive solution to some military problems that previously put the war fighter in harm's way. Since it is unmanned, the Predator UAV was operated in entirely new risk regimes previously considered too dangerous for manned aircraft. Predator was transformed into the first modern Unmanned Combat Air Vehicle (UCAV) when the Hellfire missile system was fitted to the airframe. New doctrine was written and unique missions were planned solely for the UCAV. Previous assumptions as to the attritable status of these aircraft have been reevaluated due to the increasing criticality of their missions. To that end, the risks to the aircraft are more effectively managed when the consequences of ballistic impact are known. Computer based modeling and analytical quantifications can better characterize vehicle responses when compared with experimentally verified results.

Ballistic tests of a Predator wing were conducted to evaluate the accuracy of the analytical models currently in place. The wing of the Predator UAV comprises approximately 60 percent of the presented area of the aircraft when seen from below. It is reasonable to assume that at some point anti-aircraft artillery (AAA) will hit this airframe component during a mission and hence the need to evaluate the ballistic tolerance of the wings.

Test objective

The primary objective of this Joint Live Fire (JLF) test was to provide data to verify and validate the vulnerability assessment of the Predator Unmanned Aerial Vehicle (UAV) composite wing to ballistic projectiles which may be encountered in its operational regime. Ballistic tests were conducted in December 2003 on four production wings. Pretest predictions were used to efficiently select threat size and test conditions.

Approach

Shot lines and pre test predictions were iteratively developed. Threats and shot

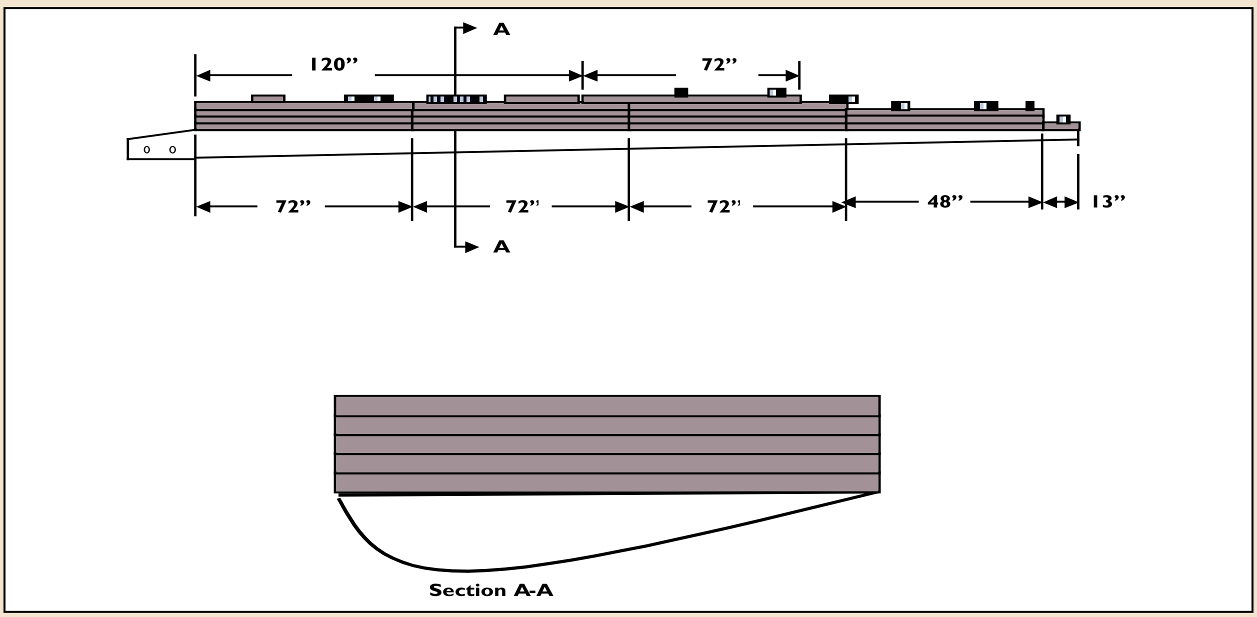


Figure 1. End and side view of rubber mat lift load simulation technique

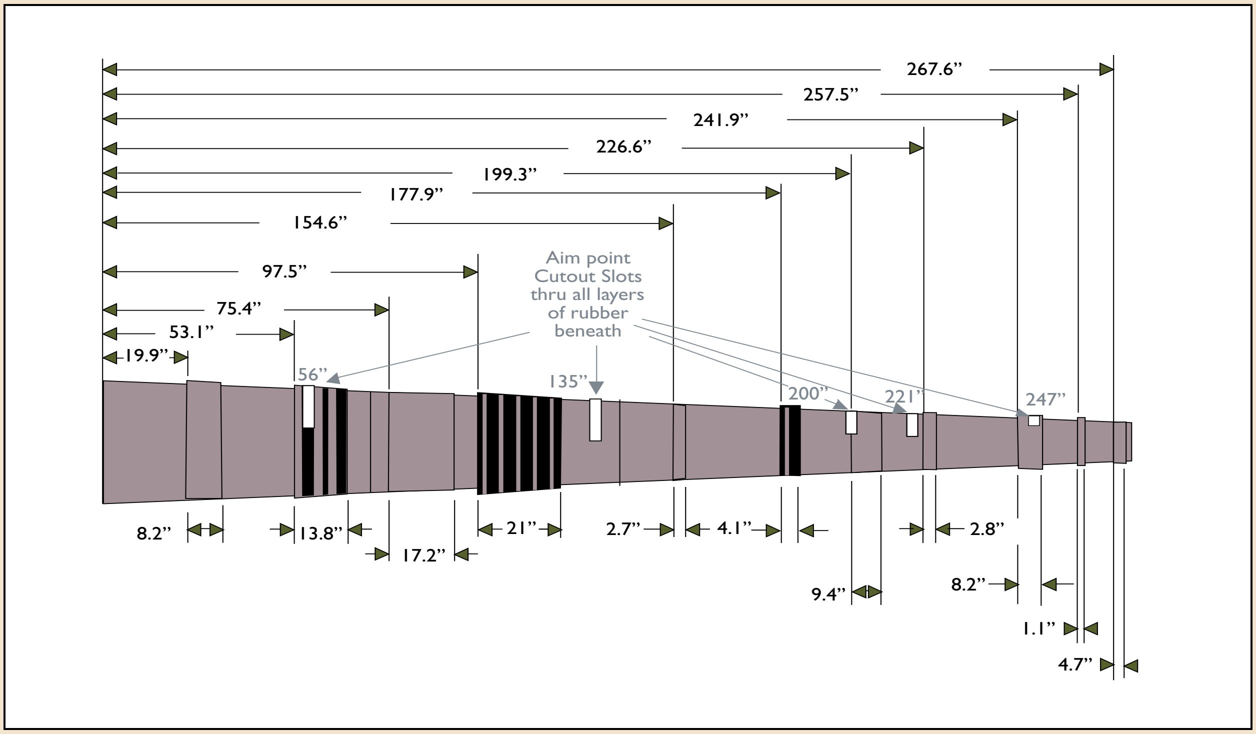


Figure 2. Top view of rubber mat lift loading simulation technique

lines were selected to challenge the wing's maximum design limit. This methodology would reveal any short-comings in the predictions and reveal areas that needed further study.

Testing was conducted at NAVAIR's Weapons Survivability Laboratory (WSL, Code 418300D) K2 ballistic test facility. The Predator wing was mounted with the flat bottom surface facing upward thus presenting its targeted surface to the gun positioned approximately twenty feet above the wing. The curved top, or projectile exit surface was facing downward. At the suggestion of an engineer at General Atomics ASI, heavy rubber mats were placed on the flat bottom surface of the wing in a prescribed manner to accurately simulate a span wise elliptically distributed lift load over the entire wing surface, thus allowing the wing skin to actively receive the simulated lift and realistically transfer it to the wing's structure (see Figure 1 and Figure 2). This simple suggestion provided an elegant solution to a difficult wing loading problem. A mobile gun tower that could be moved by a forklift (see Figure 3) was utilized to obtain the prescribed steep shot line angles.

In general, larger caliber projectiles hit near the root, smaller projectiles near the tip. The rationale for this method was that moment loads experienced by the wing were greater at the wing root than near the tip. In essence, an attempt was made to

Figure 3. Mobile gun tower and Predator wing

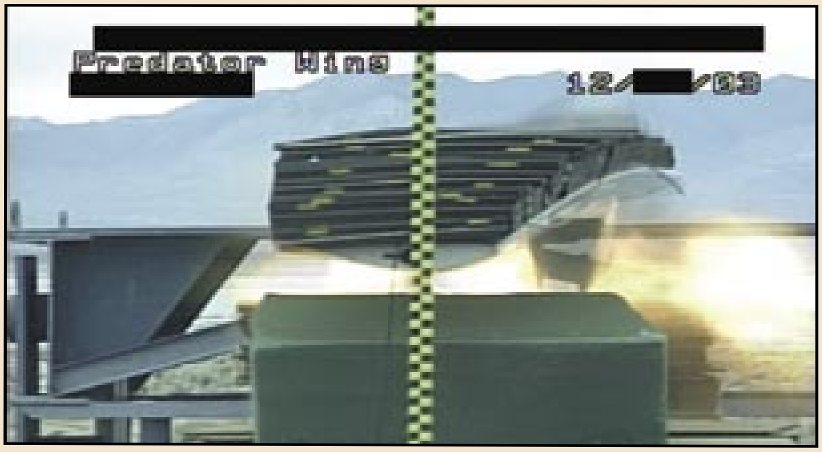


Figure 4. An unspecified threat hits the Predator wing

evenly match the design strength of the wing to the destructiveness of the threat. However, after discussing this test with the Predator designers, it was discovered that stress loads in the wing were designed to exactly match the loads placed upon it at every location in order to give precedence to an overarching concern for minimal aircraft weight.

Variables in this test included threat size, shot line selection, wing tip deflection, and delamination effects caused by ballistic damage. After some selected shots the wing was deflected beyond its one G loading to discover effects that simulated operational loads would have upon a damaged wing.

Results

The main purpose of this test was to evaluate the vulnerability of this wing under load. Vulnerable areas of the Predator UAV wing were identified and threat sensitivity thresholds established. Pre-test predictions were shown to be accurate about 80 percent of the time, but further investigation is required to validate this claim. In addition, failure modes for threshold threats that did not immediately kill this component were tested and are currently being analyzed. Test results showed that this wing construction is more robust than previously thought. Data are still being processed from all nine shots and damage effects are being carefully analyzed, but it appears that design changes that may affect future aircraft will be gained from this test. Future tests may be conducted to investigate other failure modes that were not studied in this test such as fatigue studies. Carbon fiber composite structures cannot be either classically or computationally analyzed or tested reliably by any laboratory method such as coupon testing in a material laboratory beyond 15 percent accuracy at best. To obtain accurate results it is more effective to simply conduct live fire testing. The empirical baseline established in this test will likely be useful as a stepping-stone to understanding failure modes of carbon fiber composite structures for the Predator, as well as any other aircraft with carbon fiber composite structure. ■

Mr. Jim Young is the Program Manager of NAVAIR's Aircraft Survivability, Vulnerability, and Safety R&D program. He is actively working on new technology for unmanned aerial vehicles (UAVs), Transport and Reconnaissance Aircraft, and helicopters. Mr. Young is active in the Joint Aircraft Survivability Program (JASPO) as a principal engineer on electronic warfare, acoustic, and UAV vulnerability reduction programs. Additionally, Mr. Young is the Platform Integration Branch Head of the Survivability Division at Patuxent River, Maryland. In this capacity, he oversees all platform survivability leads and chem/bio engineering.

Previously, Mr. Young was the Electronic Combat lab manager for the Air Combat Environment Test and Evaluation Facility (ACETEF) located at Patuxent River. He oversaw the test and evaluation of a great variety of Army, Navy, Marine Corp, Air Force, and Foreign electronic combat systems.

Mr. Neil J. Hamilton is a Vulnerability Reduction Engineer working for Aircraft Survivability at China Lake, California. Current projects include the JLF Predator Wing Ballistic test and the Ionomer Phase III testing which involved self-sealing technologies as applicable to UAV scale composite structures. Neil recently produced a high-speed video (shot at 30,000 frames per second) of a hydrodynamic ram event occurring in a clear Ionomer tank.

Previously, Neil was a Crew Chief on the F–117 Stealth Fighter while stationed at Holloman Air Force Base. He was assigned to the Eighth Fighter Squadron where he worked both on the flight line and in the Phase Dock. He has been deployed to Kuwait twice in support of Operation Southern Watch.

F/A–18 JLF Results Used

in Design of the F/A–18E/F

■ *by Mr. J. Hardy Tyson*

There have been many requests over the last year asking about the benefits of Joint Live Fire (JLF) Testing. Each of the platforms tested under JLF benefited in various ways, but the benefit gained by the F/A–18E/F was priceless. The F/A–18 was unique in that towards the end of JLF testing, talk of a follow on variant called the Super Hornet started rolling through NAVAIR. This was as a result of the A–12 program being canceled. The original Super Hornet briefings came as an unsolicited proposal from what was then McDonnell Douglas, the prime contractor for the F/A–18. The early pace of the program was rapid because after the A–12 was canceled the Navy still needed a replacement for the A–6.

The program quickly became the F/A–18E/F. During the conceptual design phase of the program, lessons learned from JLF testing were readily embraced by the lead vulnerability engineer at McDonnell Douglas, Mr. Mike Meyers. Mr. Meyers almost single-handedly is responsible for incorporating the design changes into the F/A–18E/F that addressed the JLF test results. These changes significantly increased the overall survivability of the F/A–18E/F.

Brief summary of F/A–18 JLF tests

Structural members vulnerability test (JLF–18–S–1)

The structural members vulnerability test made use of pre-production assets, which at the time, were known as Full Scale Development (FSD) aircraft. To support this test, two inboard wings and one outboard wing were used. The inboard wing is the part of the wing extending from the fuselage to the wing fold. This portion of the wing carries fuel and is subject to hydrodynamic ram. The wing outboard of the fold is dry. The objective of this test was to evaluate the structural integrity of the wing when impacted by large high explosive incendiary (HEI) projectile threats. The goal was to determine if the wing would catastrophically fail, resulting in loss of the aircraft. The wings did not catastrophically fail. The tests demonstrated that the multi-aluminum spar construction of the wing, with mechanically fastened composite skins, were survivable because the multi spar structure provides redundant load paths, and skin damage was attenuated at the fastener lines.

Aerodynamic surfaces vulnerability test (JLF–18–FC–2)

The aerodynamic surfaces vulnerability test made use of one vertical stabilizer attached to the fuselage, and three horizontal stabilators separately mounted on a stand, with the ability to move the stabilator in airflow. At the time, it was thought that aircraft loss might occur if a single horizontal stabilator or single verti-

cal stabilizer were to catastrophically fail and depart the aircraft. With this in mind, the objective of this test was to evaluate the structural failure of these components from HEI projectiles. The vertical stabilizer, having the same basic construction as the wing, was very tolerant to damage. However, the existing design of the horizontal stabilator attachment proved to be vulnerable.

Wing fuel system explosion vulnerability test (JLF–18–F–1)

The wing fuel system explosion vulnerability test utilized two wing box simulators and two inboard wings, which is where the explosion suppression foam is installed. The objective of the test was to evaluate the explosion suppression foams ability to suppress explosions initiated by fragments and high explosive incendiary projectiles. The explosion suppression foam proved very effective at limiting explosion overpressure in the wing.

Fuselage fuel system vulnerability test (JLF–18–F–2)

The fuselage fuel system vulnerability test used two complete fuselages to evaluate the potential for sustaining dry bay fires caused by fragments and armor piercing incendiary and high explosive incendiary projectiles. All keel shots into the bottom of the fuselage fuel tanks resulted in sustained dry bay fires. It was also learned that avionics boxes provide good shielding by absorbing lots of energy from penetrators and explosions. It was also noted that the self-sealing capability of the lower portion of the feed tanks did not perform well.

Hydrodynamic ram vulnerability test (JLF–18–F–3)

The hydrodynamic ram caused by fragments and armor piercing incendiary and high explosive incendiary projectiles, was evaluated concurrently with the fuselage fuel system vulnerability test. It was learned that the tough keel areas of the fuel tank structure performed better than the sides of the fuel tank structure. It was also determined that the inlet/fuel cell common wall needed better protection.

Fuel leakage vulnerability test (JLF–18–F–4)

The fuel leakage, specifically fuel starvation/fuel migration caused by fragments and armor piercing incendiary and high explosive incendiary projectiles, was also evaluated concurrently with the fuselage fuel system vulnerability test. It was clear that improvements were needed in the self-sealing capability.

Flight control system mechanical components vulnerability test (JLF–18–FC–1)

The flight control system mechanical components vulnerability test was a physical components evaluation. The test made use of a complete RA–5C, two partial F/A–18 fuselages, two complete F/A–18 fuselages, and a full up wing. The objective was to evaluate component failure as a result of impacting fragments, armor piercing incendiary, and high explosive incendiary projectiles. Two lessons learned were, that there is good redundancy and separation of mechanical components and hydraulic lines; and that the mechanical back-up system can be jammed causing the stick to jam, preventing the fly-by-wire system from operating. Although there is not much shielding around the cockpit, the avionics is able to absorb lots of energy—both penetration and high explosive, and if placed around the cockpit, could afford protection of the pilot.

Hydraulic fire and secondary effects vulnerability test (JLF–18–H–1)

The hydraulic fire and secondary effects caused by fragments and armor piercing incendiary and high explosive incendiary projectiles, were evaluated concurrently with the flight control system mechanical components vulnerability test. The objective was to evaluate the ability of the above listed threats to produce hydraulic fluid fires. It was demonstrated that the F/A–18's reservoir level sensing works well and few hydraulic fires were generated.

Hydraulic system components vulnerability test (JLF–18–H–2)

Damage to hydraulic system components caused by fragments and armor piercing incendiary and high explosive incendiary projectiles, was also evaluated concurrently with the flight control system mechanical components vulnerability test. It was learned that individual hydraulic system components are easily damaged, but redundancy minimizes impact on the aircraft as a whole.

F404 engine core/case failure vulnerability test (JLF–18–P–1)

The general electric F404 engine core/case failure vulnerability test used non-operating engine components and a full up running engine, to evaluate torching and structural failure of the engine from fragments and armor piercing incendiary and high explosive incendiary projectiles. No pronounced torching occurred; and it was demonstrated that larger threats could lead to catastrophic engine failure resulting in aircraft loss.

F404 engine bay vulnerability test (JLF–18–P–2)

The F404 engine bay vulnerability test made use of two F/A–18 fuselages, two engine simulators, and one running F404 engine. The objective of this test was to evaluate the capability of fragments and high explosive incendiary projectiles that cause engine bay fires. It was learned that the outside of the engine case and components are not hot enough to cause hot surface ignition. The airframe mounted assessory drive (AMAD), which is in a separate fire zone, keeps some flammables away from the engine. Most importantly, it was learned that engine mounted accessories are vulnerable, because their liquids were consistently ignited by threat flash/incendiary. All high explosive incendiary shots resulted in engine kills.

F404 fuel ingestion tolerance vulnerability test (JLF–18–P–3)

The fuel ingestion tolerance test used simulators, one F/A–18 fuselage and two running engines to evaluate the fuel ingestion tolerance due to fragment, armor piercing incendiary and high explosive incendiary damage to the inlet/fuel cell common wall. It was learned that; better common wall protection was needed. Torching can cause aircraft loss, not just engine loss. Severe engine damage occurs whether the fuel is ingested by the fan or the engine.

F/A–18 full-up vulnerability test

A full-scale, full up development aircraft was used for this test. The test evaluated any synergism, cascading damage, and helped fill data voids from the previous testing; but no duplication of previous tests was attempted. It was learned that the fly-by-wire flight control system degrades gracefully when the flight control computer is shot. It was observed that avionics provides good shielding. Damage to a loaded gun ammunition drum is survivable, but foreign objects could damage the engine. The accessory drive area is also vulnerable to fires.

As a direct result of JLF testing on the F/A–18 the following potential improvements to the vulnerability posture were identified—

1. Improved protection of the engine air-inlet duct/fuel tank common wall.
2. Active dry-bay fire protection in keel areas.
3. Improved design of the horizontal stabilator attachment point.
4. Improved separation of hydraulic lines and flight control system lines.
5. Elimination of the mechanical flight control back-up system.

The F/A–18E/F program ultimately selected the following list of vulnerability reduction features to ensure the aircraft met the ballistic vulnerability design requirements of the F/A–18E/F.

1. Addition of dry bay fire protection beneath fuel tanks 2, 3, and 4.
2. Redesign of the horizontal stabilator outer bearing attachment point.
3. Relocation of the primary and secondary heat exchanger aft, allowing rerouting of the hot-air bleed duct.
4. Relocation of hydraulic reservoirs to the bottom fuselage; reduction in length of previously vulnerable hydraulic lines routed vertically between the reservoir and pumps.
5. Improved materials lay-up for the engine air-inlet duct/fuel tank common wall.
6. Further separation of flight control system hydraulic lines between the vertical tails.
7. Continued use of explosion suppression foam in the wing.
8. Elimination of the mechanical back-up flight control system and replacement by the horizontal stabilator fault management system.
9. Substitution of polyalphaolefin radar cooling fluid for the older, even more flammable fluid.

It is especially important to note that *all* of the improvements identified during JLF testing were incorporated in the F/A–18 E/F.

For the F/A–18 E/F program, McDonnell Douglas did not shy away from the newly passed Live Fire Test Law, but committed to complying with the Law from the beginning. During Live Fire Testing of the F/A–18 E/F aircraft, the design performed well, proving the worth of the design improvements identified during Joint Live Fire Testing. This means that the F/A–18 E/F will be bringing our men and women pilots home even after sustaining combat damage. ■

Mr. J. Hardy Tyson received his Bachelor of Science in Mechanical Engineering from Walla Walla College in 1983. He has worked in the Survivability Division at the Naval Air Warfare Center Weapons Division, China Lake for 20 years. He was the Live Fire Test/Vulnerability Test Lead for the F/A–18E/F program. He is currently working Live Fire Test and Vulnerability on the F–35 program. He may be reached at 760.939.8416 or by e-mail at j.tyson@navy.mil.

Combat Survivability Division Presents

Annual Survivability Awards

■ *by Mr. John Vice*

The National Defense Industrial Association's (NDIA) Combat Survivability Awards for Leadership and Technical Achievement were presented to Mr. James B. Foulk and Dr. Lewis A. Thurman, respectively, at the Aircraft Survivability 2003 Symposium held November 3–6, 2003 at the Naval Postgraduate School (NPS), Monterey, California. These awards, presented annually at the NDIA Combat Survivability Division's Aircraft Survivability symposium, recognize individuals or teams demonstrating superior performance across the entire spectrum of survivability, including susceptibility reduction, vulnerability reduction, and related modeling and simulation.

Combat Survivability Award for Leadership

The NDIA Combat Survivability Award for Leadership is presented to a person who has made major contributions to enhancing 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 this award is on demonstrated superior leadership of a continuing nature.

Mr. James B. Foulk, President, SURVICE Engineering Company, Aberdeen, Maryland was the 2003 Leadership Award recipient. Mr. Foulk was recognized for exceptional leadership in the field of aircraft combat survivability. Drawing on his extensive experience in aerospace vehicle and engine ballistic survivability, Mr. Foulk planned and managed a number of key research and development programs and special analyses over the years. He has actively participated in national coordinating and joint working groups in this field, is recognized as an authority on air weapon system survivability analyses, and has been a key contributor and leader in development and application of survivability enhancement features and assessment processes. For example, his contributions to the design of survivability features for Apache and Blackhawk helicopters have been well proven in combat, and were directly responsible for saving lives of aircrewmen during the recent wars in Afghanistan and Iraq. Mr. Foulk was also a principal founding member of the NDIA Combat Survivability Division and was instrumental in the establishment and development of the Department of Defense Survivability/Vulnerability Information Analysis Center (SURVIAC). Under his leadership as founder and president of SURVICE Engineering, the company has become widely recognized throughout Government and industry as a highly valued aircraft survivability resource.

Combat Survivability Award for Technical Achievement

The NDIA Combat Survivability Award for Technical Achievement is presented to a person or team who has made a significant technical contribution to any aspect of survivability. It may be presented for a specific act or contribution, or for exceptional technical performance over a prolonged period. Individuals at any level of experience are eligible for this award.

Dr. Lewis A Thurman, Head, Tactical Systems Technology Division, MIT Lincoln Laboratory, Lexington, Massachusetts, was the 2003 Technical Achievement Award recipient. Over the years, Dr. Thurman

Apache AH-64E

Aircraft Survivability 2003 Award recipients from left to right: Roland P. Marquis, Chairman, Awards Committee, Combat Survivability Division; James B. Foulk; Dr. Lewis A. Thurman; and RADM Robert H. Gormley, USN (Ret), Chairman, NDIA Combat Survivability Division.

Blackhawk

pioneered the development of credible analytic processes for assessing the survivability of modern U.S. weapon systems. At the outset of the stealth aircraft era, a number of critical phenomenology issues needed to be addressed and studied. The U.S. Air Force Special Projects Office Red Team then approached Dr. Thurman at the Massachusetts Institute of Technology Lincoln Laboratory where, as head of the Tactical Systems Technology Division, he designed programs and experiments definitively answering many of these questions. Later, as the warfighting community moved to precision munitions, Dr. Thurman's team performed key experiments examining the impact on weapons accuracy of external effects such as intentional GPS interference. He led his team during the development of Lincoln Laboratory's Airborne Seeker Test Bed, which provides essential information on the effectiveness of surface to air missiles. Under his leadership, as Head of the Lincoln Laboratory Tactical Systems Technology Division, Lincoln Laboratory's definitive work on Electronic Countermeasures effectiveness demonstrated what works and what doesn't, and this work is now recognized as the foundation for most of the mission planning systems in use today. As a result, combat crews may now plan with realistic expectations. Through Dr. Thurman's meticulous scientific approach, the Division has earned an undisputed reputation for experiment credibility.

Best Poster Paper Awards

Awards were also presented for the best poster papers displayed as part of the symposium's Exhibits and Poster Papers feature. Three awards were presented. First place went to Mr. Ronald Dexter, SURVICE Engineering Company, Dayton, Ohio for his paper "Fire Prediction Model—Development and Applications," second place went to Ms. Debra Wilkerson, Naval Air Warfare Center—Weapons Division, China Lake, California for her paper "Aircraft Protection Against the MANPAD Threat: Countermeasure Solution and Comparison to Field Tests," and third place went to Mr. Daniel Cyphers, Skyward, Ltd., Dayton, Ohio for his paper "From Concept to Demonstration—The Evolving Enhanced Powder Panel." ■

Tutorials Popular at Aircraft Survivability 2003

■ *by Mr. John Vice*

Aircraft survivability-related tutorials are becoming an increasingly popular feature of the National Defense Industrial Association's (NDIA) annual Aircraft Survivability symposium. The tutorials are aimed at newcomers to the combat survivability discipline, but are also of interest to experienced members of the community, who like a periodic update on the state-of-the-art.

Held on the day preceding official commencement of the symposium, the tutorials were presented as a prelude to Aircraft Survivability 2003. This year's tutorials, held in the Mechanical Engineering Auditorium, Building 245 North at the Naval Postgraduate School, Monterey, California, attracted the highest attendance ever. Over 80 attendees at each of the two tutorials presented, took advantage of the opportunity for continuing education, and updates on the state of the art in aircraft survivability.

The morning was devoted to "An Introduction to the Aircraft Survivability Discipline," presented by Dr. Robert E. Ball, Distinguished Professor Emeritus, Department of Aeronautics and Astronautics, Naval Postgraduate School, Monterey, California. In the afternoon, Lt Col Anthony E. Brindisi, USAFR, and Maj David Bartkowiak, USAFR, of the 46 OG/OGM/OL-AC, Wright-Patterson AFB, Ohio, presented "Joint Combat Assessment Team Threat Awareness Training."

The morning tutorial was an introduction to the aircraft combat survivability discipline that, focused on this year's symposium theme, "Reclaiming the Low Altitude Battlespace." It presented the history, concepts, terminology, facts, procedures, requirements, measures, methodology, and technology, for the non-nuclear combat survivability analysis and design of fixed-wing and rotary-wing aircraft, unmanned air vehicles, and guided/cruise missiles. It was based upon the recently published 2nd edition of Professor Ball's American Institute of Aeronautics and Astronautics textbook "The Fundamentals of Aircraft Combat Survivability Analysis and Design." Specific topics included: An Overview of the Fundamentals, An Historical Perspective, Survivability Assessment, Designing for Survivability, Survivability Modeling and Simulation, and Testing for Survivability.

The threat awareness training was an intense hands-on approach to educating the warfighter and Department of Defense contractors on threat warheads and their effects on fixed and rotary wing aircraft. It was the perfect complement to the vulnerability reduction portion of Professor Ball's morning tutorial. Through the effective use of multimedia visual aides and an extensive collection of exploited hardware, the attendees gained an understanding of the capabilities of small arms, anti-aircraft artillery, MANPADS and rocket propelled grenades, and the ability to recognize a threat based on characteristic damage patterns. This training, which is constantly updated, utilized the most recent combat engagement data available. By having a keener sense of damage recognition, intelligence officers are better prepared to assess and report on theater threats; maintainers are better prepared to quickly turn an aircraft; mission planners gain a more thorough knowledge of what the aircrews are facing; air-

Professor Ball presenting his tutorial at Aircraft Survivability 2003 craft vulnerability reduction engineers are better equipped to design and/or modify U.S. combat aircraft to reduce their vulnerability; and, ultimately, aircrew members are better equipped for survival.

Based on the results of surveys completed by attendees of each of the two sessions, the attendees were highly pleased with the education and training they received in the tutorials. A day of topical, tailored tutorials will again be presented on November 30, 2004 in advance of Aircraft Survivability 2004 scheduled for December 1–3 ,again at the Naval Postgraduate School, Monterey, California.

An introduction to the aircraft survivability discipline

Instructor—Dr. Ball worked in the aerospace industry in the early 1960s. In 1967, he joined the faculty of the Department of Aeronautics at the Naval Postgraduate School in Monterey, California. His textbook "The Fundamentals of Aircraft Combat Survivability Analysis and Design," was sponsored by the Joint Technical Coordinating Group on Aircraft Survivability (JTCG/AS) now JASPO, and published in 1985, by the American Institute of Aeronautics and Astronautics (AIAA). In 1989, Dr. Ball established the AIAA Survivability Technical Committee, and in 1991 he served as Chair of the National Research Council's Committee on Weapons Effects on Airborne Systems. In December 1997 he appeared as an expert witness at the National Transportation Safety Board's public hearing on the TWA Flight 800 mishap. Dr. Ball retired from the Naval Postgraduate School in November 1998 as a Distinguished Professor. The second edition of Dr. Ball's textbook has recently been published.

Lt Col Brindisi and Maj Bartkowiak showing typical hands-on threat awareness training props at Aircraft Survivability 2003

Aircraft Survivability 2003 Tutorial attendees listening to the presentation

Joint Combat Assessment team threat awareness training

Instructors—Lt Col Tony Brindisi is the Program Manager for the Joint Combat Assessment Team (JCAT), building the team into a 20-plus person inter-service program. He has 23 years of experience in the areas of low observables, operational effects, and aircraft vulnerability reduction, and has been instrumental in the analysis of combat encounters with U.S. aircraft from Desert Storm, Operation Allied Force, Operation Enduring Freedom, and Operation Iraqi Freedom. Maj Dave Bartkowiak has 15 years of aerospace experience covering everything from weapons effects against ground structures, to aircraft battle damage repair and aircraft structural engineering. He has been a member of the JCAT for five years performing threat weapons analyses of combat engagements from Vietnam to the present. Maj Bartkowiak also directs the Threat Awareness Training Program for the JCAT. ■

Future Combat Systems

The Army's Survivable Force for the 21st Century

■ *by Mr. Jamie Childress, Mr. Jim Russell, and Mr. Tim Williams*

What is FCS?

See first. Understand first. Act first. Finish decisively.

This is the motto of the Army's Future Combat Systems (FCS). FCS is an Army/Defense Advanced Research Projects Agency (DARPA) program awarded to the Lead Systems Integrator team of Boeing/SAIC. It is a networked system of systems (one large system made up of numerous individual systems plus the network, plus the soldier) that includes Manned Ground Vehicles (MGVs), Unmanned Ground Vehicles (UGVs), Unmanned Air Vehicles (UAVs), and a wireless battlefield network that connects all of these hardware platforms with Land Warrior–equipped soldiers in an integrated fighting force.

FCS will be configured in Units of Action (UA), which consist of approximately 2,500 personnel and 350 manned platforms. The UA is 100 percent mobile and completely self-sufficient for up to 72 hours of high-intensity contact on delivery into the area of operations. The networked FCS systems provide each UA commander with the combat leverage to make contact with, and defeat, numerically superior forces employing equal or better individual weapons systems. The UA combined arms teams, down to platoon level, possess FCS systems that amplify their combat effectiveness: organic sensors; weapons effects; Intelligence Surveillance and Reconnaissance (ISR) capabilities; and wireless communications at each echelon, to link to the joint Command Control Communications and Computer Intelligence Surveillance and Reconnaissance (C4ISR) system.

FCS will augment and gradually replace part of the current fleet of "heavy" vehicles—the Abrams tanks (about 70 tons each) and Bradley Fighting Vehicles (about 33 tons each), with a new family of MGVs and unmanned vehicles weighing substantially less. The lighter, smaller FCS vehicles are designed for transport in a C–130, which allows them to be flown to a conflict anywhere in the world within 96 hours, rolled off and ready to fight.

There are eight types of MGV variants, seen below in an artist's rendering: the MV (Medical), FRMV (Recovery), RSV (Reconnaissance), NLOS–C (Artillery Cannon), MCS (Tank), NLOS–M (Mortar), C2V (Command and Control), and ICV (Infantry Combat Vehicle). All variants have the same common systems (engine, suspension, crew stations, etc.) and variant specific mission hardware (cannon, surveillance optics, etc.).

FCS system of systems approach to survivability

The C–130 deployability requirement of FCS vehicles dictates that the survivability of the manned vehicles cannot be ensured through the use of armor alone. FCS force survivability will be ensured through the use of network centric warfare tactics that provide dramatically increased situational awareness and lethality, combined with state of the art protection systems on the vehicles. The FCS wireless network uses advanced communications technologies to link soldiers with both manned and unmanned ground and air platforms and sensors. A soldier, linked to these platforms and sensors, has access to data that greatly enhances survivability by showing where their friends are, where the enemy is, and providing evidence of what the enemy is doing based on the history of their recent maneuvers. Soldiers can command lethal fire from their own vehicle, or direct it from other vehicles in the network, including the ability to direct missiles from a distant module to coordinates they select. This approach allows individual vehicles to benefit from the collective survivability and lethality of an entire force. Figure 2 lists the systems survivability elements of the FCS force,

Figure 1. FCS MGV variants

Figure 2. FCS MGV survivability elements

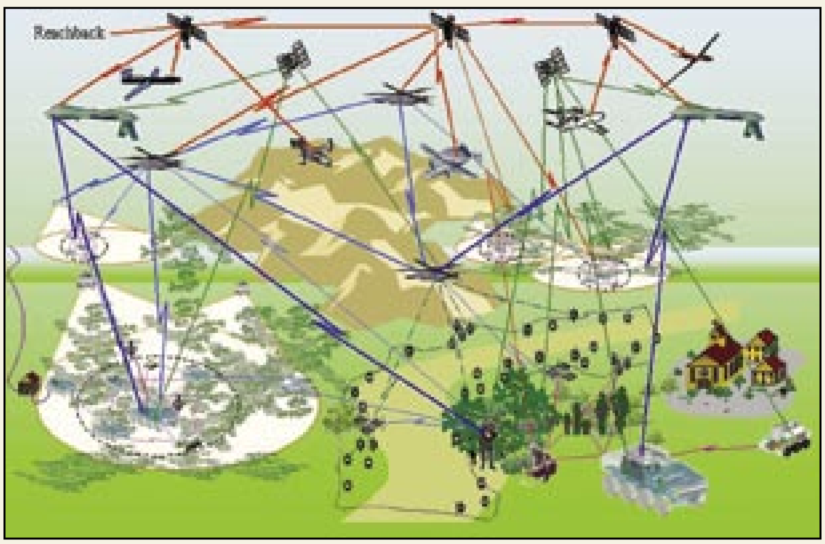


Figure 3. FCS system of systems network

and Figure 3 shows the battlefield connectivity of the network.

In theory, this ability to see first (over the horizon), understand first (via the network of sensors and shared data), and act first (also over the horizon), means the opposing forces will be greatly reduced, if not completely neutralized before manned ground vehicles make contact. The system of systems, that is FCS, will exhibit high lethality in this stand-off mode, resulting in greatly decreased threat levels faced by the manned ground vehicles and their soldiers. FCS will also have means to defend against the opponent's stand-off weapons, including a network-enabled avenge-kill capability.

In practice, there will be some leakage through this offensive fence, leading to a need for defensive capabilities native to each vehicle variant. Though these defensive capabilities can also be used in a networked fashion, all manned ground vehicles are designed to be highly survivable by themselves.

MGV platform survivability

Although in most engagements the survivability of an individual MGV will be enhanced through the System of Systems effects, each vehicle must also have a core of native survivability features to protect it from local threats. Though they have different mission-based defensive needs, each MGV variant will have a tailored, self-protection suite that includes some aspects of advanced armor protection, systems hardening, signature management, active and passive countermeasures, NBC protection, protection processing, and advanced prognostics. Figure 4 (see page 51) lists these main MGV platform protection technologies.

Advanced armor

The M–1 Abrams main battle tank weights about 70 tons. Much of that weight is due to the heavy steel armor, which is capable of defeating a variety of anti-tank threats. Due to the FCS C–130 transport requirements, the FCS MGV "flight weight" is only about 19 tons. This weight ceiling eliminates steel armor as a viable option.

To reduce the weight of the required armor, advanced ceramic armor designs are being used. The armor is comprised of an outer layer of ceramic over a structural shell. The armor is highly integrated into the vehicle structure to further reduce weight, and produce a light-weight vehicle with superior ballistic hardening. Pound for pound, the FCS MGVs will have the most space and weight efficient armor package ever fielded on a ground vehicle.

In addition to armor integrated into the hull, add-on armor packages may be installed to increase both ballistic protection and mine blast protection. The vehicle structure is designed with the high structural strength required to accept add-on armor packages capable of defeating large caliber threats and anti-tank mines. The combination of inherent vehicle armor and the ability to easily upgrade the armor package provides superior protection and preserves the high mobility required of the FCS force.

Countermeasures

Because of the weight restrictions, it will not be possible to defeat large anti-tank weapons with armor alone. The FCS MGVs will be protected against many anti-tank threats using active countermeasures including obscurants, decoys, jamming, and direct interception of incoming threats. This defensive approach to threats that overmatch the structure of the vehicle is similar to the approach taken by the aircraft community, and in fact many of the same components have been borrowed or adapted.

Before countermeasures can be employed, the presence and nature of imminent threats must be determined, leading to the integration of threat warning sensors in the FCS defensive capability. In the case of the initial FCS concepts, these were derived from aircraft threat sensors such as the AN/VVR series laser warning receiver, and the CMWS missile warning sensor. The sensors will be modified to some extent for application to ground vehicles, packaged in housings robust against small arms, and use algorithms tailored for the ground environment, but will be functionally equivalent to their aircraft predecessors.

Countermeasures employed by FCS ground vehicles will also bear strong similarity to the countermeasures employed by aircraft. FCS ground vehicles will dispense decoys, chaff, and smoke. They will employ various kinds of jamming, and launch lethal counter-munitions to defeat RPGs or ATGMs. Like aircraft, these active countermeasures will be deployed from within an enclosure with doors or covers designed to protect them from the ambient environment, and maintain effective signature management when closed. When weapon systems target FCS vehicles, these defensive components will rapidly deploy to reduce the risk posed by the threat.

Signature management

As with aircraft, it is more combat effective not to be targeted in the first place, or at least deny first detection capability – and therefore first shot capability – to the enemy. At a top level, the key to signature management is consistency. Vehicles are detected and become targets because they are distinct from non-targets, and this distinction can arise from several types of cue. Maintaining a low detectability means appearing consistent with the foreground and background features of the environment – whether that means bushes, sand dunes, or an unchanging clear cold sky.

Signature managed vehicles (ideally) appear consistent within a scene – as for example the view through a weapons sight, or the scene observed through a pair of binoculars, or on a radar screen. Within any scene, the vehicle must not stand out as different – either by having too much or too little contrast, exhibiting unique spatial or geometric features, or creating a recognizable disturbance, or other impact on the local environment. This quality of scene-consistent appearance must extend across all the vehicles in the Unit of Action so that as the larger scene is considered, no part of the friendly force will be detectable – which would call attention to other potential targets in the vicinity, or invite examination of the region by fire.

A vehicle's appearance must also be consistent over time without sudden changes due to operational modes, maneuver, deployment of weapons or mission equipment, the embarkation or debarkation of soldiers from infantry fighting vehicles, or the influence of weather or the diurnal cycle. This temporal consistency is most important, of course, for combat vehicles which intend to occupy fixed locations for a significant period of time, since they may be compared with their immediate surroundings multiple times. In motion, such temporal cues are less important, but instantaneous consistency with the random statistics of the scene must still be maintained.

A scene is often observed through different types of sensor – human eyes, night vision imagers, infrared imagers, radar, and perhaps other modes. Consistent appearance across spectral bands can be more difficult to achieve, than scene-consistency within any one spectral band, but as opposing forces begin to employ multi-spectral detection techniques, the maintenance of spectral consistency, or spectral balance, will become increasingly important.

Finally, soldiers must bear in mind the benefits of maintaining a signature consistent with their own combat actions and tactics. There is no sense in maintaining a highly scene-matched signature while firing the main weapon, since that signature will greatly dominate their own. On the other hand, if the tactics being employed call for passing over, or through enemy territory without engagement, then signature management would be an essential element of successful tactics.

The FCS force is structured to employ all these aspects of signature consistency when fully configured, using a variety of technologies and component materials.

Protection processing systems

Advanced signature management, countermeasures, and the ability to monitor the threat environment, are not sufficient by themselves to assure enhanced protection – threat engagements must be anticipated, predicted, and the best course of action calculated. Threat sensors can be employed to determine what type of threat is approaching, and library data describing functional attributes can be used to compute likely risk of damage to the platform. This calculation requires accurate and current information about the state of the platform, the conditions of the environment, and the availability of countermeasures.

- Managed observables
- Lightweight armor
- Active countermeasures
- Mine resistant
- NBC capable
- Distributed prognostics
- Protection processing
- Multi-Threat hardening
- Robust structure
- Mobility assurance
- Networked C4ISR architecture

Figure 4. Platform protection technologies

Processing this information appropriately requires an internal engagement model i.e., a real-time physics-based model of what would be likely to happen if the present threat weapon were to impact the platform, at the predicted impact location, and to what extent a given countermeasure could reduce that risk. The engagement model need not be overly complex, but it must accurately reflect the vulnerability of the platform to a range of typical threats, must be able to estimate a time-to-go, and be able to anticipate the results of typical threat/countermeasure interactions. In addition, the internal model should represent the relevant prevailing environmental and operational conditions such as day/night, moving/stopped, open terrain/defilade, urban/forest – or, alternatively, day/night, high altitude/low altitude, cloudy/clear, bay doors open/closed, etc. for the aircraft environment. This environmental representation in the internal engagement model is used to modify the estimated risk posed by the converging threat, and to modify the anticipated interaction between the threat and the countermeasure.

In many threat/countermeasure engagements, time is limited. This is particularly the case for ground vehicles because interaction distances are often quite short. Aircraft are not often threatened by platforms which fire from distances of dozens or hundreds of meters, but ground vehicles experience these threat ranges routinely, leading to a need for immediate reactions.

One way to provide rapid response from a protection processor is to compute a range of likely threat scenarios in advance; that is, the processor resolves questions such as, "what would be the best response if an ATGM were to appear from 45 degrees at a range of 250 meters right now?" This hypothetical prediction capability allows the processor to populate a table of best responses—and update it every second or so. Therefore, as conditions, environments, or force configurations change, the table will always hold a nearly-best answer ready for immediate execution.

FCS/JAS survivability coordination

Traditionally, ground vehicle survivability was largely driven by armor. Conversely, aircraft survivability was driven by susceptibility reduction, and vulnerability hardening. The conventional wisdom has been that the two communities have little in common and thus, little to offer each other. FCS challenges that paradigm. Although the FCS ground vehicles are not aircraft, they are being designed from the ground up to be air transportable. Thus, in many respects, they must live by the same weight and design guidelines as air vehicles. The survivability technologies developed by the Joint Aircraft Survivability (JAS) community can, and should, be applied to FCS vehicles, wherever appropriate. At the same time, many of the advanced technologies developed for FCS could prove valuable to both fixed wing and rotorcraft.

Conclusion

This introduction to the FCS program is intended to start the conversation between the aircraft and FCS survivability communities. As noted here, there are more than passing similarities between survivability in the aircraft world and in the design of FCS. We look forward to hearing about the survivability advances made by JAS programs, and sharing with you the advances made on FCS, as well as opportunities to combine, merge, or collaborate on the development of needed and mutually applicable technologies and tools. ■

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Calendar of Events

JUL

11–14, Ft. Lauderdale, FL
40th AIAA/ASME/SAE/ASEE Joint Propulsion Conf/Expo
www.aiaa.org

AUG

3–5, Reno, NV
Unmanned Systems 2004
www.aiaa.org

16–19, Providence, RI
AIAA Modeling and Simulation Technologies Conf/Expo
www.aiaa.org

26–29, Anaheim, CA
Annual Reliability and Maintainability Symposium (RAMS)
www.auvsi.org

29–2 Sep
Test and Evaluation: Integral to the Systems Engineering Process Test Week 2004
michael.mcfalls@rdec.redstone.army.mil

NOV

30–2 Dec, Monterey, CA
Aircraft Survivability 2004–Survivability within the Integrated Battlespace
www.ndia.org

15–18, Lisbon, Portugal
The Fourth Triennial International Aircraft Fire and Cabin Safety Research Conference
www.caa.co.uk/srg/intsd/event.asp

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

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